Scottish Universities Research & Reactor Centre

AN AIRBORNE GAMMA RAY SURVEY OF PARTS OF SW SCOTLAND IN FEBRUARY 1993. FINAL REPORT

D.C.W. SANDERSON, J.D. ALLYSON, A.N. TYLER,
S. NI RIAIN, S. MURPHY

East Kilbride Glasgow G75 OQF Telephone: 01355 223332 Fax: 01355 229898

EXECUTIVE SUMMARY

An airborne gamma ray survey was conducted for the Scottish Office Environment Department of coastal and inland parts of SW Scotland to define existing background levels, to locate features worthy of further attention, and to demonstrate the emergency response capabilities of radiometric methods. Coastal areas were surveyed with 500 m line spacing. Inland areas were specified to 2 km line spacing, however it was possible to achieve 1 km line spacing in the majority of the inland zone.

Fieldwork was conducted between the 1st and 16th February 1993. A total of over 17,000 gamma ray spectra were recorded, using a 16 litre NaI spectrometer mounted in a helicopter flying at 50-75m ground clearance and 120kph. A total area of 3650 km^2 was surveyed in 41.6 flying hours, from roughly 4370 line kilometres. The data were reduced in the field using standard SURRC procedures for background subtraction, stripping of spectral interferences, altitude correction, and calibration. Preliminary maps of the distribution of ^{137}Cs, ^{40}K, ^{214}Bi, ^{208}Tl, and estimated ground level gamma dose rate were produced during the fieldwork period using working calibration values derived from previous surveys. A set of core samples was collected from Wigtown Merse, Longbridgemuir and Caerlaverock merse for calibration purposes, and aerial observations were performed at these sites.

Further soil sampling and ground level in-situ gamma spectrometry was performed in the summer of 1993 to investigate the applicability of the calibration to a range of upland soil types and topographical environments. These locations received peak deposition from the Chernobyl accident, are vulnerable to wet deposition, and are difficult to monitor rapidly using ground based methods. A total of 76 soil cores, subdivided into 168 separate samples was thus collected for high resolution gamma spectrometry in the laboratory. This was conducted from April to November 1993.

For the terrestrial sites the aerial survey estimates based on the working calibration, were in good agreement with both in-situ gamma spectrometry and the results of core analysis. This validates the preliminary maps in these contexts, and confirms that a general calibration is sufficient for fallout mapping under emergency response conditions. On coastal salt marsh sites (merse), where aged deposits of Sellafield derived activity have accumulated, subsurface activity profiles for ^{137}Cs and ^{241}Am and the presence of superficial levels of ^{134}Cs were observed from the soil cores. Similar features have been observed in previous surveys. In these cases the effects of source burial must be taken into account to avoid underestimation of activity levels by both ground-based and aerial gamma spectrometry. A separate set of detailed maps for the principal merse sites was therefore prepared using a calibration factor derived from the soil cores from this context. There are prospects for developing spectral analysis procedures to account for source depth in aerial surveys. Source burial on the merse also has implications for sampling techniques, and for dose rate measurement, which would merit further consideration.

The radiometric maps show clearly the distributions of each individual nuclide and indicate the contribution which individual localised features make to the overall gamma ray dose rate. Naturally occurring nuclides reflect the underlying geological and geomorphological contexts of the landscape. The main granite intrusions, most notably at Cairnsmore of Fleet, the Loch Doon Granodiorite, Glencairn of Carsphairn, the Dalbeattie granite, and Criffel Pluton are

readily visible in ^{40}K, ^{214}Bi and ^{208}Tl maps, and control their local radiation environments. A number of areas of enhanced ^{214}Bi, which may reflect radon potential, were noted. A transient radon associated ^{214}Bi signal was observed on the west of the Wigtown peninsular during the survey. Examination of spectral data in the vicinity of Dundrennan has confirmed that there is no evidence of widespread terrestrial contamination arising from the use of depleted uranium projectiles on the range.

The ^{137}Cs map indicates the environmental distribution of this nuclide in considerable detail. Levels of ^{137}Cs range from approximately 2 kBq m^{-2}, a level consistent with global weapons' testing fallout, from 2-40kBq m^{-2} on terrestrial sites affected by deposition from the Chernobyl accident, and from 40 kBq m^{-2} to over 200 kBq m^{-2} on tide washed pastures which have accumulated marine sediments from the Irish Sea. All three levels are represented within the survey zone, in a manner which is consistent with the findings of previous aerial surveys in adjacent areas, and with ground based studies.

The main Chernobyl deposition in Dumfries and Galloway appears to have occurred between an area just east of the Nith, and Glenluce. The northern limit has not yet been defined, and there may be grounds for considering extension of the northern and particularly eastern limits of the inland survey zone. Within the survey zone the deposition pattern is complex, including both upland and lowland components. The plume trajectories for deposition inferred from these observations are oriented northwards rather than in the NW directions predicted by meteorological derived estimates. This may explain the contradiction between results from the Central Highlands and the estimated fallout patterns. The data presented here both add to previous knowledge, and serve as a baseline against which any future changes can be measured.

The survey provides systematic coverage of the sedimentary and terrestrial coastal system for the first time, and has identified a number of merse sites which have accumulated radioactivity from past marine discharges from Sellafield, and which are not routinely monitored under existing Scottish Office arrangements. Some of these locations are extensive and fall within SSI's; furthermore they are key sites for studying future deposition trends. It would seem prudent to review radiological assessments in the light of this work to ensure that the patterns of occupancy and sensitive ecologies of the merse are taken fully into account.

The emergency response potential of aerial radiometrics has been clearly demonstrated in this project. It provides the only practical means of providing comprehensive environmental measurements of remote and upland landscapes on a short time scale, with an effective area sampling density some 10^6-10^7 times greater than soil sampling. Results are compatible with ground based approaches, and could focus ground based efforts effectively under emergency conditions. Modern approaches to data recording and analysis are able to produce maps during the survey period. National baseline mapping in Scotland, at 1 km resolution, would require less than 800 flying hours; 20 km line spacing would take roughly 40 hours of flight time. A long term programme of high resolution national baseline mapping, coupled to an emergency response standby arrangement, would provide an extremely cost effective way of preserving the capability developed since the Chernobyl accident, while producing high quality environmental data for research purposes.

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1. INTRODUCTION

This report describes fieldwork and preliminary results of an aerial gamma ray survey conducted in SW Scotland by SURRC, for the Scottish Office Environment Department (HMIPI), in February 1993. The aims were to define the present gamma ray background in both coastal and inland areas in Dumfries and Galloway to serve as a reference against which future changes can be measured, and to identify any local anomalies requiring further detailed investigation. The survey areas were defined in advance, contract specification being to examine coastal and intertidal areas from the Nith to Burrow Head, with approximately 500 m line spacing, and to examine inland areas to the West of the A713 with 2 km line spacing or better. A further objective was to demonstrate the potential of the aerial survey method for rapid mapping of large areas, with a view to it's national emergency response role.

Aerial radiometric techniques are well suited to large scale environmental surveys, and are highly complementary to subsequent ground based investigations[1,2]. Their main strengths derive from the mobility of the observational platform, in this case a helicopter, and the spatial response of the detector, which averages signals over a field of view which can extend to several hundred metres[3-5]. By recording a sequence of gamma ray spectra in flight, interleaved with navigational data and radioaltimetry, it is possible to map the radiation fields above a survey area. This leads to a highly effective means of locating areas of enhanced radiation, especially in remote locations or difficult terrain [6-9]. The method can be applied to total area searches at regional or national level[10-14] , and the remote sensing nature of such measurements minimises exposure of survey teams to contamination or radiation hazards. These considerations, together with the speed of measurement, typically more than two orders of magnitude faster than ground based approaches, lead to important potential contributions to emergency response planning and implementation [14-18].

The ability to work in a complementary manner with ground based teams is no less important, allowing limited conventional resources to be effectively directed to areas of greatest need. Ground based in-situ spectrometry is capable of high spatial resolution and sensitivity, and leads naturally to sampling for investigation of radionuclide profiles and chemical speciation. However these methods alone are not particularly effective for large scale surveys due to their inherent lack of speed and low sampling densities. The combination of aerial observations and ground based studies, including sampling of key areas, provides a powerful approach to a comprehensive evaluation of the radiation environment.

The radiation environment of SW Scotland has been under study for many years, mainly for the purposes of environmental research. There has been considerable interest in the spread of anthropogenic nuclides discharged from Sellafield into the marine environment, and their impact on intertidal sediments [19-21], and potential transfer routes to the terrestrial environment[22-26]. It is also recognised that SW Scotland includes areas which received relatively high deposition from the Chernobyl accident[27-30], resulting in livestock movement restrictions. Most previous studies of environmental radioactivity in this area have been conducted using ground based techniques, of necessity resulting in limited spatial detail. Brief aerial survey studies were conducted in the Wigtown peninsular and Mull of Galloway in 1988, using a DAFS fixed wing aircraft and prototype SURRC spectrometer[11], to validate the feasibility of mapping UK fallout levels from the air. Occasional coastal observations have subsequently been made in the Solway en-route to other UK surveys[12,13,16], however this study represents the first comprehensive aerial survey of this major part of Dumfries and Galloway. In juxtaposition with the adjacent areas of Ayrshire[14], mapped with 1 km line spacing in 1990, and the inner Solway[17], mapped with 500m line spacing, this creates a unique UK data base for environmental radioactivity levels in South-West Scotland.

Section 2 of this report describes the survey specification, preparations and fieldwork. Both aerial survey and ground based sampling are dealt with, together with a description of the methodologies for reducing radiometric data in the field. The basis of the working calibration used to produce preliminary maps from the survey is discussed. The survey and initial sampling were conducted in February 1993, preliminary maps being reported in March. Further ground based measurements and core sampling were undertaken in August to provide a ground to air comparison for a series of upland and inland contexts.

Section 3 presents the radiometric maps for the entire area which are unchanged since the preliminary report, and discusses their main features. The results of high resolution gamma spectrometry from the core samples collected during and after the aerial survey are presented and discussed, demonstrating the validity of the original working calibration for inland sites, and concordance with ground based measurements along an EW transect. For tide washed pastures, showing pronounced radiometric signals due to deposition of Sellafield contaminated sediments, the core results confirm the presence of significant sub-surface activity profiles. Such source profiles result in the attenuation of primary gamma-ray intensity and build-up of scattered radiation. This leads both in-situ and aerial survey results to underestimate total activity per unit area if terrestrial calibration factors are used. Corrections for this effect were used to prepare a set of detailed maps showing ^{137}Cs distribution on selected salt marshes.

The original maps of the natural sources showed an enhanced radon signal on the NW side of the Wigtown peninsular near to Glenluce. Observations during the survey suggested that this was a transient effect, related to the weather conditions during the survey, and not to a local geological source. A carborne survey was conducted in early September 1993, in order to investigate this feature. This is also shown in section 3, confirming the expected transient nature of the signal. Finally some public concern has been expressed following media discussion of the possible effects of the use of depleted uranium on the Ministry of Defence gunnery range at Dundrennan. The survey flew over this range at 500 m line spacing. A retrospective analysis of the spectral data from the range and it's adjacent coastal areas was conducted to establish whether or not there was any evidence for enhanced levels of the uranium daughter ^{234m}Pa.

Section 4 presents a discussion of the main survey findings and conclusions. This deals with the features revealed by the survey, the relationships between radiometric and conventional activity estimates, and the use of these results to guide future ground based environmental studies. Aerial survey can be seen to be a extremely effective way of defining the radiation background of a large region at modest cost per unit area, and in an appropriate timescale for emergency response purposes. The manner in which radiometric surveys of this sort can increase the effectiveness of conventional approaches to both emergency response and to long term studies, including baseline mapping and detection of change in the radiation background is discussed.

2. FIELDWORK AND ANALYSIS

2.1 Survey specification

The survey area and timescale for fieldwork were defined following correspondence with the Scottish Office at the end of 1992. The priorities were to conduct initial fieldwork in February 1993, thus enabling preliminary results to be available at the end of March, and to investigate both coastal and inland areas with varying spatial detail. The total area for investigation is shown in figure 2.1, subdivided into three parts labelled A, B, and C.

Area A comprises the coastal zone and intertidal limits of major rivers from the Nith in the east to beyond Burrow Head in the West. The survey objective was to record gamma ray spectra with 500m line spacing from this area to define marine sedimentary and tide washed areas, together with their terrestrial contexts, with effectively total coverage. During fieldwork the NW boundary of this zone was extended northwards and 2 km east, to include the intertidal limits of the River Cree at high resolution. Areas B and C were specified at 2 km line spacing, to maximise both the area covered, and the probability of completing this task within 14 flying days. In the event it was possible to better this target throughout the majority of these areas. The aims here were to define the levels of naturally occurring and fallout nuclides in inland zones, including upland areas, which are both susceptible to recycling Cs isotopes through the food chain, and are costly and difficult to monitor at ground level due to inaccessibility. Significant mountain ranges within the region were included in these areas (Merrick, Carsphairn, Glencairn of Fleet), providing a practical test of the feasibility of operating aircraft in such zones in winter months.

A 16 litre NaI gamma spectrometer was used as the main detector, coupled to an SURRC instrumentation rack and data logging system. The instrument was mounted in an Aerospatiale Squirrel helicopter chartered from PLM helicopters (Glasgow) from 1st to 16th February 1993. The spectrometer includes a Navstar XR4 global positioning system (GPS) satellite navigation facility, used both to label gamma ray spectra with latitude and longitude, and to provide navigational information to direct the aircraft along survey flight lines. Ground clearance was measured by radioaltimetry.

The nuclides of interest were ^{137}Cs, ^{40}K, ^{214}Bi, ^{208}Tl and ^{134}Cs if detectable. Gamma ray dose rates were also estimated by scaling count rates above 450 keV, in accordance with the survey specification, and with the international standard "total count" approach.

The use of the integral above 450 keV for dose rate estimation avoids the low energy region where (i) the photon fluence at aerial survey heights is dominated by scattered radiation, and (ii) there is a high photoelectric interaction probability with the detector leading to a highly energy dependent dose response function relative to air kerma. As shown by previous work [3] the dose response of ground based NaI detectors to natural sources within such an integral is independent of the K, U, or Th contents. Ground to air comparisons have verified that there is a good correlation between aerial dose rate estimates from the >450 keV integral and (a) ground based calibrated NaI detectors (b) routine dose rate instruments for the range of environmental sources encountered in this survey. The extent to which such an approach can deal accurately with complex nuclide mixtures, or unusual distributions or scattering conditions is not entirely clear. The EG&G aerial survey group have demonstrated excellent

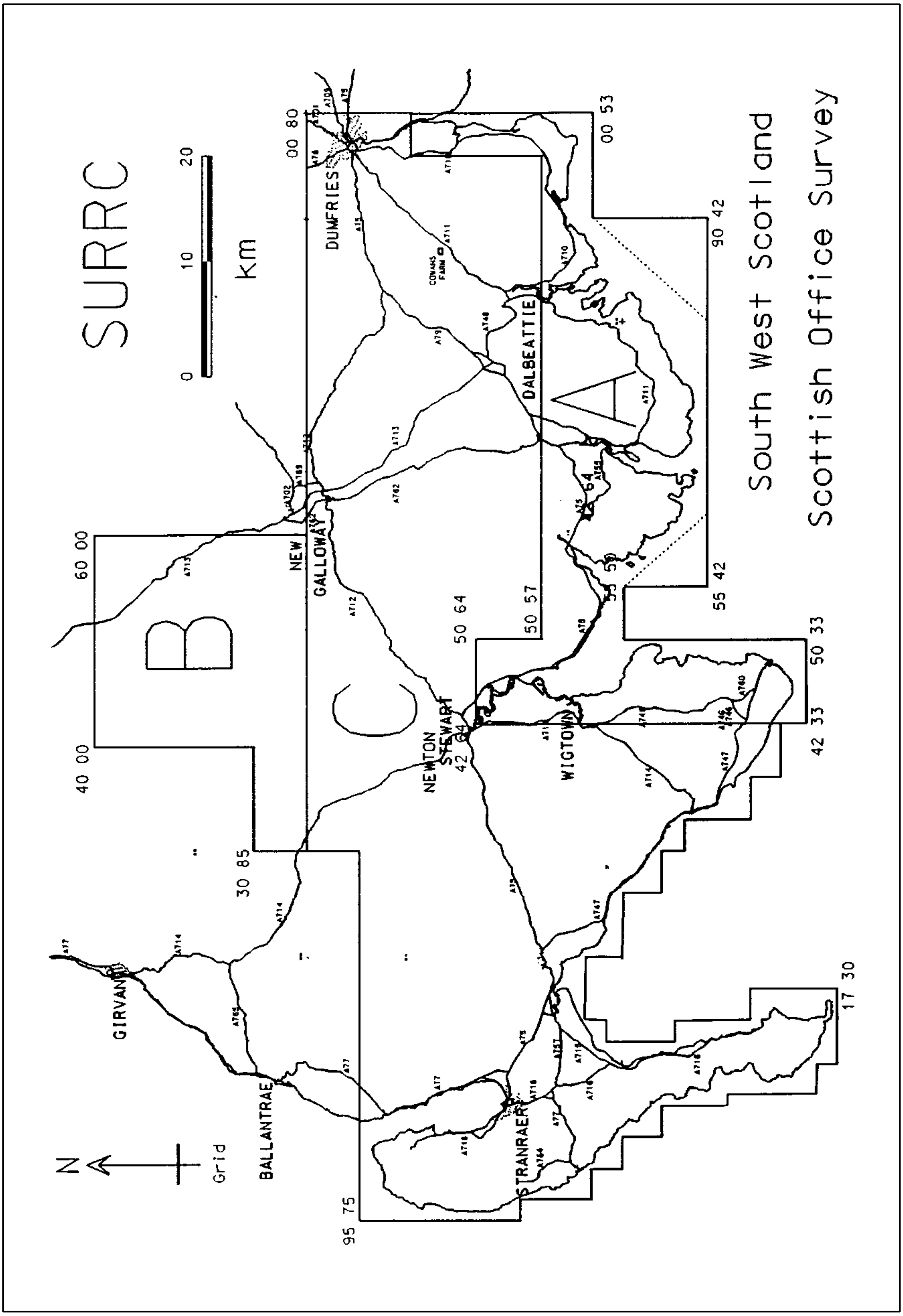


Figure 2.1 Map Illustrating Areas A, B and C of Survey Area

agreement between aerial survey exposure estimates and ground level measurements using pressurised ionisation chambers on many nuclear sites with diverse sources and scattering conditions. It is however possible to postulate conditions where alternative methods based on full spectral analysis would be preferable.

2.2 Preparation

Preparatory work included comprehensive laboratory testing of the spectrometer, preparation of survey maps and flight plans, establishing a fieldbase, and installation and flight testing of the spectrometer. These tasks took place prior to fieldwork at the beginning of February.

The detector response to pure spectral sources of activity was defined using a calibration facility at SURRC comprising four 1 metre square concrete blocks, undoped and loaded with known concentrations of potassium, and equilibrated sources of U and Th series activity. These calibration sources for natural radioactivity[30] were supplemented by a 1 m^2 ^{137}Cs source prepared at SURRC. Spectra were recorded from each source with and without a series of 20 1 cm thick 1 m^2 perspex absorbers used to simulate scattering in an air path, and each equivalent to 9.6 m of dry air at STP. Stripping factors were calculated describing the fractional interferences between standard integration windows (see appendix A) for each nuclide of interest, from each pure spectral source. The stripping factors for ^{134}Cs were defined using a standard reference solution.

A fieldbase at Cowans Farm near Kirkgunzeon was established, and supplementary equipment, including equipment for ground sampling, computers for data reduction, a spare NaI array and a second radiometrics rack was transported to the base on 30th January. The location of this fieldbase, to the SW of Dumfries and in the eastern part of area C (see figure 2.1) was taken into account in planning flight lines. A decision was taken to orientate the main 2 km flight lines in the central part of area C EW, while those in area B and in western and eastern parts of area C were arranged in a NS direction. This enabled most flights between Cowans farm and the other parts of areas A, B and C to be used productively as part of the survey. PLM helicopters arranged for drum fuel supplies to be placed at Cowans Farm, near Newton Stewart and near Stranraer. The combination of strategically located fuel supplies and the flight line disposition described above was intended to maximise the survey data collected within the flying budget available. This approach proved highly successful and allowed us to achieve 1 km line spacing through the majority of areas B and C. Flight maps were prepared and marked with the positions of waypoints at the start and end of each target flight line. Latitude and Longitude values for each waypoint were programmed into the Navstar GPS system before each flight and used to direct the pilot.

The detector was installed in the aircraft at Glasgow airport on 31st January 1993, and tested functionally. High voltage to the detector was maintained subsequently at all times, using supplementary mains power while standing by, internal batteries during engine start-up and the aircraft 28 V dc supply during flight. The aircraft was transferred to the fieldbase at Cowans farm on 1st February 1993, flight testing and radioaltimeter calibration being performed relative to barometric reference at Glasgow Airport before departure.

2.3 Radiometric Survey Fieldwork

The fieldwork itself was conducted from Cowans Farm between the 1st and 16th February 1993. Weather conditions were extremely still, with relatively high atmospheric pressure (1035-1028 mbar) throughout the period. This resulted in slowly moving low cloud and fog for much of the survey period, limiting access to the higher ground until the last stages of the fieldwork. The survey was progressed as far as possible to utilise the weather opportunities which existed. Thus upland zones were explored in the first week whenever possible, but the majority of the coastal area was tackled first, reflecting accessibility.

Daily checks of the spectrometer energy resolution at 662 keV were made using a 370 kBq ^{137}Cs reference source positioned under the aircraft. Individual crystal gains were trimmed where necessary to meet the target of 12±1% or better resolution. Trimming was necessary for the first few days of the survey as the crystal temperatures equilibrated with external ambient conditions. Thereafter daily checks showed no further changes in resolution.

The spectrometer background was initially recorded at the start of each day's flight, either at low altitude over a freshwater Loch, or over sea at survey height. Background readings were slightly higher than expected, however a stable pattern emerged over several days work, and it was concluded that the aircraft used carried a small natural background due to U and Th impurities in or on the airframe. By the 9th of February a stable background had been observed sufficiently to calculate weighted mean values for all nuclides of interest. Thereafter regular checks were continued, essentially for comparison with these mean values.

Flights were conducted for sorties of up to 3 hours, flying at ground speed of 60-80 knots, and ground clearance of approximately 75 m. Gamma ray spectra were recorded with 5 second integration in area A, and 10 second integration in areas B and C, interleaved with GPS latitude and longitude positions, and time averaged radioaltimetry. Integrated count rates were evaluated in real time, together with their associated Poisson statistical errors and displayed on the operators screen. A continuous on-line gain monitor was achieved by integrating the 1462 keV ^{40}K full-energy gamma ray peak into two symmetrical halves whose count rate ratios, and associated statistical errors were evaluated and presented on screen at all times. Any significant long term deviations from unity indicate gain drift, enabling small real-time corrections to be made to the spectrometer. Gain stability to better than approximately 1% was thus maintained throughout the survey. This is considerably better than the energy resolution of the detector, and previous studies have demonstrated that the subsequent spectral processing steps are robust to such small shifts.

Navigation was assisted by pre-programming the latitude and longitude of flight line ends into the Navstar XR4 GPS, which thereafter provided indications of true bearing, ground speed, cross track errors and range for the end of each flight line. The GPS precision, operated in stand alone mode, was typically better than ±30-50 m, and almost invariably better than 100m. We are aware of certain systematic differences between GPS position estimates in the OSGB 36 datum, and the OSGB 36 latitude and longitude scales applied to 1:50000 OS maps. These are usually small compared with the precision of individual GPS readings. It is possible to record position to a precision of better than 5m using real-time differential GPS with a telemetry link between the aircraft and a ground based reference station. Such a system was tested successfully by SURRC in September 1992 during a survey of the Ribble estuary [18]. However it is noted that the field of view of the detector (90% of the signal originates from within a circle of diameter 4-5 times survey altitude) is greater than the navigational error of stand alone GPS, and that unless line spacings of less than 100m are required the differential GPS approach is not needed.

Flights within each day were conducted subject to satisfactory weather, pilot's statutory rest periods, and daylight hours. This entailed usually two sorties per day, resulting in the production of several Mbytes of primary data. These results were backed up in duplicate using QIC standard tape streamers for all primary records, and 3.5" high density floppy discs for reduced data. All data copying routines included verification that the results were readable. In addition to these copies of the data a complete record of the primary archive was formed on a secondary ground based computer by overnight restoration of the previous day's flight data, before clearing the spectrometer hard disc for the following day's flights. Regular field reports were prepared summarising survey progress and transmitted to HMIPI by Fax on the day of each flight.

At the end of the field work period over 17,000 gamma ray spectra had been recorded in 41.6 hours of flying, including the return transit to Glasgow. This completed all survey targets specified. Area A was flown with essentially complete coverage at 500m resolution. Areas B and C were completed with 1 km line spacing throughout the majority area, and approximately 2 km spacing over the Mull of Galloway. This exceeded the 2 km specification by a considerable margin. Preliminary data reduction (see below) was carried out in the field, and early maps of the area A results prepared for viewing on computer screen as the work progressed. It was thus possible to review results with HMIPI before the end of the fieldwork, both in digital and mapped forms.

A series of ground based in-situ spectrometer readings, and core samples was taken at three sites, as follows, to assist with calibrating the survey.

i) A standard SURRC 31 point helicopter calibration site had been prepared on the merse at Caerlaverock National Nature Reserve in February 1992, in support of an earlier survey of the inner Solway[17]. This site was re-visited at ground level on the 4th February 1993, and a single central in-situ gamma spectrum recorded. A set of observations from the helicopter above the central point at heights of 50,100,150,200,300 and 400 feet was taken on the 2nd February 1993 to provide traceability for the working calibration of the survey.

ii) A second merse calibration site was prepared at Wigtown merse (OS grid reference NX 441555) from 7th-9th February. Thirty one 105mm diameter cores were collected to a depth of 30 cm from an expanding hexagonal pattern, and was used to define the effective activity inventories seen from the helicopter at aerial survey heights. A set of calibration observations from the helicopter was taken at this site on 7th February at a range of heights.

iii) A set of cores was collected at Longbridgemuir (NY 056 694) to the east of Dumfries, to form a third calibration site by extending earlier SURRC sampling (in the summer of 1992) to form an expanding hexagon to aerial survey dimensions. This site is an inland wetland, site whose main environmental radioactivity signal is due to Chernobyl fallout, the natural radioactivity from underlying rocks being obscured by the significant waterlogged organic overburden. Aerial survey calibration measurements were made on the 15th February

1993.

The calibration factors for Cs nuclides are particularly sensitive to the vertical activity distribution on a given site. While interpretation is easy in the immediate aftermath of a deposition event, when fresh sources of activity are effectively exposed close to the ground surface, the possible effects of aged deposition on calibration require careful consideration. An additional set of sites on upland soils within the survey (particularly areas B and C) was investigated after the survey (see section 2.5.2) to examine the extent to which a general calibration for ^{137}Cs could be applied to the terrestrial contexts.

The samples collected were all returned to SURRC for sectioning and drying, prior to homogenisation and high resolution gamma spectrometry.

2.4 Preliminary Data Analysis

Standard SURRC data analysis procedures were followed both during and after the fieldwork period. The first stage of data processing, which takes place in the aircraft prior to downloading the spectrometer, is the formation of summary files describing each flight. The summary files themselves contain a sequential record of the individual spectral observations, collated with time averaged altitude measurements and interpolated estimates of the central latitude and longitude. Integrated gross count rates for six preselected regions of interest are included. Summary file records are formed automatically by a search programme, initially from the integrated count rate data calculated in real time during the flights. Formation of supplementary sets of summary files, reintegrated into extra or different windows, can be performed retrospectively, although this was not needed during the fieldwork on this occasion. Summary files were formed to extract count rates for ^{137}Cs, ^{134}Cs, ^{40}K, ^{214}Bi, ^{208}Tl and >450 keV photons. All summary records were printed out during the fieldwork and examined briefly for quality assurance purposes and to identify key features.

Subsequent data analysis took place using the summary files, linked together to form extended records within each survey area in a manner that described the complete survey. Subtraction of measured detector background rates formed a set of "net" count rate files. The application of a 5x5 matrix stripping procedure using coefficients defined by pure element calibration measurements at SURRC, applicable to a 80 m equivalent air path, produced a set of stripped count rate estimates for the 5 nuclides of interest, together with the total count rate data (>450 keV). These results were then corrected for measured altitude variations, using exponential altitude corrections with coefficients derived from experiments over calibration sites during previous surveys, and calibrated by scaling to a working calibration derived from earlier work.

The calibration factors used to produce preliminary results from this work were defined by reviewing past data recorded with the same spectrometer at previous calibration sites. This included four sites in Ayrshire [14], which carried detectable levels of ^{137}Cs in peaty soils with low and variable natural radioactivity, the Caerlaverock site [17], and Warton Marsh on the Ribble Estuary [18], where the inventories of ^{137}Cs both show pronounced sub-surface maxima. Theoretical estimates based on numerical integration of photon fluences calculated for surface and volume sources were also reviewed. The quality of data on natural nuclides is less satisfactory than for ^{137}Cs, since the natural signals from peaty sites are poorly described by a finite set of cores (and relate more to the variable degrees of overburden on top of subsoils), and the saltmarsh calibration sites contain variable sedimentary components. After reviewing available data it was concluded that working values from previous surveys could not be bettered at present; however the possibility of systematic under-response for ^{137}Cs in merse contexts was noted, due to source burial. The values of calibration constants selected during the fieldwork are shown in appendix A. The calibration equations relate stripped, altitude corrected, count rates for each nuclide to activity per unit area integrated to a depth of 30 cm from the ground surface. Natural nuclides have been additionally related to activity concentration (Bq kg^{-1}). The present scheme does however allow for a direct comparison between activity levels of natural and anthropogenic nuclides. Calibrated levels of ^{134}Cs were for the most part below minimum detectable levels (approx. 1 kBq m^{-2}), and have not been mapped further. However it was noted that coastal merse sites showed small enrichments (apparently up to 3-4 kBq m^{-2} ^{134}Cs), which may be a reflection of Chernobyl run-off adding slightly to the marine derived activity or Sellafield derived component. It was felt that this could be better investigated at a site specific level using high resolution spectrometry.

The calibrated data for the complete survey comprised over 17,000 observations, exceeding the capacity of the standard SURRC mapping software for analysis in 6 variable format. To overcome this the results were separated into a set of 6 pairs of "XYZ" files, using the SURRC "AERO" software, each describing OS 6 figure eastings and northings for each observation, relative to a working origin at position NX 500,500, together with calibrated values of each individual radiometric variable. Prior to formation of "XYZ" files the positional information was transformed from latitude and longitude into OS 6 figure units, using local interpolations to the OSGB 36 datum, including corrections for small angle rotation relative to the 1:50,000 map sheets. The "XYZ" files were subsequently used to produce colour maps of the data, again in the "AERO" package, results being printed on a Tektronix 4697 colour printer at SURRC, and collated to form maps of the whole survey.

During map formation it was noticed that data from one sortie, conducted in the afternoon of 2nd February, were discordant with adjacent tie lines and surveys in the eastern edge of area B, and the transit line north of Cowans Farm and on the NE edge of area C. Examination of spectra from within this flight confirmed that the gain of one of the four NaI crystals had apparently moved independently from the other three crystals resulting in (i) a split ^{137}Cs peak, with 25% of 662 keV appearing the ^{134}Cs window, (ii) similar interference between ^{40}K and ^{214}Bi windows. Further examination of spectra recorded earlier that day, and the following morning confirmed that this feature did not occur at other times in the survey. It was attributed to initial gain drift in one of the crystals, which had been substituted for a faulty crystal before the start of survey, and had not equilibrated at bias with the others. A split ^{137}Cs peak had been noted during resolution checks the following morning, and corrected by re-trimming. There was no further evidence of this phenomenon thereafter. After consideration it was decided to adopt the following remedies. (i) The flight lines affected were re-stripped with a modified stripping matrix which suppressed the spurious stripping of excess ^{214}Bi and ^{134}Cs counts into the ^{40}K and ^{137}Cs window. (ii) The re-stripped data were matched at tie locations with observations from other flights within the survey, and calibrated to give compatible results. (iii) The results for ^{208}Tl, and total gamma dose rate were unaffected by these procedures. (iv) ^{137}Cs and ^{40}K results after correction were compatible with adjacent observations. (v) It was not possible to correct ^{214}Bi results from this line, and therefore these results were removed from the relevant "XYZ" files, and omitted from the maps. If necessary a short repeat flight would be able to replace these results, and examine the northern and eastern boundaries of the Chernobyl signals.

2.5 Ground Sampling

2.5.1 Calibration Sites

The calibration procedures adopted in this, as in previous SURRC aerial surveys depend on characterisation of spectral stripping parameters using reference facilities (concrete calibration pads supplemented by absorbers and additional anthropogenic sources), and determination of system sensitivities by direct ground to air comparisons in the survey zone. This represents an extension of the international standard methods for geological mapping, and ensures that environmental factors relating to the source distribution are taken into account[32,34,35]. The use of core samples analysed by high resolution spectrometry for the ground based analyses provides traceability to international reference materials. However in adopting this approach it is important to recognise that the airborne detector at 100 m altitude samples some 10^7 times more material than a typical 2 kg soil sample. Calibration sites therefore must be selected and sampled to : i) spatially match the field of view of an airborne detector for various altitudes, ii) account for the within site variability, and iii) examine source depth characteristics within the soil or sediment profile.

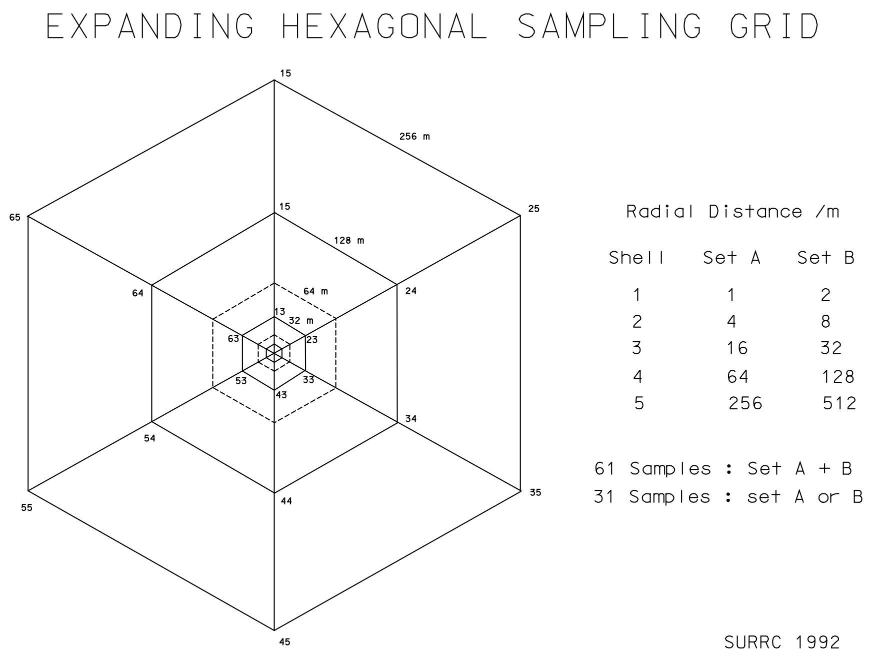


Figure 2.2 Expanding Hexagonal Sampling Grid

The calibration sites are based upon the expanding hexagon pattern shown in figure 2.2. Core samples are collected at the centre of the site and at the apexes of each hexagonal shell whose radial dimensions expand out in logarithmic intervals (eg. x2 or x4). Thus sample spacing increases for each successive shell. In this instance samples are collected at 2, 8, 32, 128 and 256 metres from the central point.

For the calibration of the aerial survey, calibration coefficients have been determined through sampling and ground to air comparisons in previous aerial surveys [12,13,14,17,18]. However, to account for environmental change in source distribution characteristics, it is important that new calibration sites are developed, within each survey area. The sites used during this survey were :

1) The Caerlaverock merse site (NX 290649). A site developed during the course of the 1992 Chapelcross aerial survey [17,32]. This site was visited by helicopter at the beginning and end of survey, confirming that the spectrometer response was indistinguishable between 1992 and 1993. Ground based in-situ gamma spectrometry at the pad centre showed that activity levels in 1993 were within 10% of those recorded in the previous year (Appendix D).

2) The Wigtown merse site (NX 441557). This site was developed to examine salt marsh (merse) characteristics in the Western (outer) Solway Firth, and thus the calibration coefficients required to represent the buried source aspects typical of these sites. Thirty one soil cores of 10.5 cm diameter by 30 cm depth were sampled at Wigtown merse. The cores spaced at 128 m apart west to east across the merse were sectioned into 0-2cm, 2-5 cm, 5-10 cm, 10-15 cm, 15-20 cm and 20-30 cm intervals to determine the soil distribution profile. Samples were otherwise divided into 15 cm intervals.

3) The Longbridgemuir Basin Valley peat site (NY 055698). To verify the existing calibration, a previous SURRC ground sampling site was extended to be used as an aerial survey calibration site. The 2 and 8 m spaced samples had previously been sampled and thus only the 32 and 128 m samples were added to the sample load during the survey to characterise spatial variability and source depth properties (in this instance to 45cm depth). Samples spaced at 128 m apart were divided into 5 cm intervals from 5 points across the site, one from the centre, and 4 from the 128 m hexagonal shell.

Thus a total of 43 soil cores were collected during the aerial survey, subsequently subdivided into 135 subsamples for high resolution gamma spectrometry.

2.5.2 Supplementary Ground to Air Comparisons

Having examined the preliminary maps it was recognised that the calibration sites did not fully represent the range of inland soils on which peak Chernobyl deposition had occurred. To investigate the possible impact upon calibration factors, a further set of 11 sites, forming an inland east-west transect across the survey zone was investigated in the last week of August 1993. The sampling sites are indicated in table 2.1 and figure 2.3.

At each location, between 7 and 8 cores sampled were collected with the 10.5 cm diameter corer to a depth of 30 cm. Samples were sectioned in 0-5 cm, 5-15 cm, and 15-30 cm intervals. A simplified version of the expanding hexagon was implemented, based on triangles, and samples were taken at 2 and 32 m spacings. In addition, up to 4 in-situ spectra (up to 1000 seconds live time) were collected per site with a 3" x 3" NaI(Tl) spectrometer to examine the degree of spatial variability. This resulted in a further 11 cores, subsequently divided into 33 samples for subsequent high resolution gamma spectrometry. In addition a further 5 single "spot" in-situ measurement sites were selected across the Wigtown Peninsula, which are clay rich sites: Gillespie (NX 247 524), Port William (NX 342 439), Larroch (NX

378 410), Chapel Outon (NX 446 420), Sorbie (NX 450 474). An extra peaty site in the Galloway Forest Park was also measured: Deer Park (NX 520 732).

Table 2.1 Field sampling locations of east-west transect

Location	Reference Name	OS Grid Reference	Date	Soil Type	Sampling Depth /m
Nutholm Farm	NUT1	NY 130 768	29/8/93	Clay	0.30
Ingleston	ING1	NX 910 789	30/8/93	Clay	0.30
Crofts Farm	CRO1	NX 794 740	30/8/93	Peat/min.	0.30
Shaw Fell	SHA1	NX 695 738	3/9/93	Clay/stoney	0.15
Benbreck	BEN1	NX 594 762	31/8/93	Peat	0.29
Curleywee	CUR1	NX 460 761	31/8/93	Peat	0.30
Drannandow	DRA1	NX 389 712	1/9/93	Clay/min.	0.20
Barford	BAR1	NX 320 650	1/9/93	Peat	0.29
Artfield	ART1	NX 230 660	3/9/93	Peat	0.29
Dunragit	DUN1	NX 151 588	2/9/93	Clay/peat	0.22
High Boreland	BOR1	NX 090 585	2/9/93	Sandy	0.30

2.6 Analysis and Traceability of Core Samples

The ground based sampling program resulted in a set of about 168 individual samples for high resolution gamma spectrometry. The samples were taken back to SURRC and dried to constant weight in a large capacity oven at approximately 50°C. A 1 kg capacity mixer-mill was used to reduce the particle size to below approximately 50 microns and to homogenize the samples. Subsamples of 30 cm^3 or 150 cm^3 were dispensed into standard containers, sealed and stored for at least 2-3 weeks prior to gamma spectrometry to enhance radon equilibration.

Gamma spectra were measured for 50,000 seconds using two 50% relative efficiency "n"-type shielded Ge spectrometers. Measurements from the samples were interleaved systematically with those from background matrices and a secondary reference standard presented to the detector in an identical manner to the samples. An additional standard sample, made from a known combination of IAEA RGU, RGTh and RGK, plus a measured amount of ^{137}Cs and ^{241}Am (derived from a well characterized saltmarsh sediment) was used to confirm international traceability. Quality assurance steps were incorporated into all stages of sample handling and analysis. Each sample was analysed under consistent conditions, and traceable records were prepared of the logging and labelling of each sample, the bulk weight,

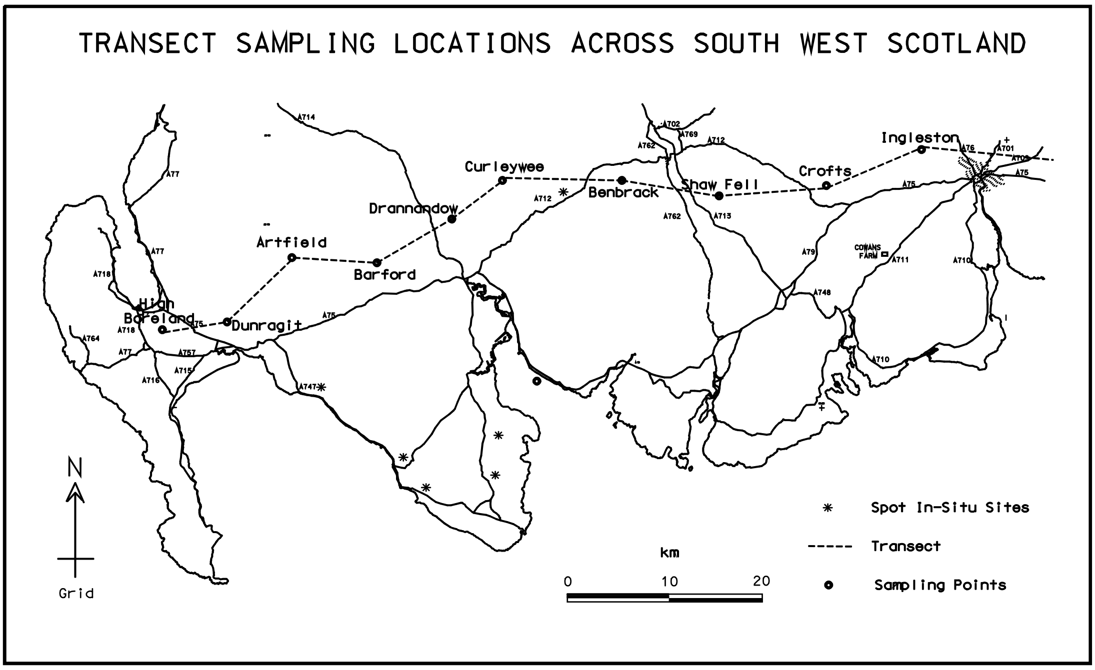


Figure 2.3 Illustrating the Transect Sampling Locations Across South West Scotland

wet weight, dry weight, sample counting geometry, detector employed, date of measurement and analytical data.

Full gamma ray spectra from 30 keV to 3 MeV were stored and analysed using Ortec software to produce report files of full-energy peak count rates for the following radionuclides:

anthropogenic nuclides -

^{241}Am (59.5 keV), ^{137}Cs (662 keV), ^{134}Cs (796 keV)

natural or technologically enhanced nuclides -
^{40}K (1461 keV), ^{214}Bi (609, 1764 keV), ^{208}Tl (583, 2615 keV) and ^{228}Ac (911, 969 keV).

Separate SURRC programmes ("GSP1REP" & "GSP2REP") were used to tabulate and assemble the results from samples and standards, and to calculate calibrated, density corrected activity concentrations and activity per unit areas as follows.

A sequential series of report files was assembled and read in to the analytical software. The report files include regions of interest (window) gross counts, net peak counts (with their associated errors), live times and labels. These were assembled into a data matrix for further analysis. Background count rates for each line were subtracted using data from silica samples analysed in identical geometry, to produce net peak count rates for each window. Each net count rate value was then divided by sample weight (kg), and multiplied by a sensitivity factor (Bq per cps) for each line defined from the secondary reference (Caerlaverock) standard. This yielded a uncorrected concentration estimate in Bq kg^{-1}. To correct for density variations in samples containing ^{137}Cs, ^{134}Cs and ^{241}Am, a linear density correction was applied. This was derived from previous analyses of a suite of spiked soils of varying density [32]. Density corrected dry concentrations (Bq kg^{-1}) for each sample are tabulated in Appendix C. Activity per unit area estimates for each depth layer Bq m^{-2} were calculated by multiplying by the dry bulk weight and dividing by core area (8.66×10^{-3} m^2). These were summed vertically across cores to obtain the inventory down to the sampling depth.

Radionuclide estimates were found to be within experimental error of prepared IAEA hybrid standards (table 3.16), except for ^{214}Bi that was approximately +30% different. This may be associated with radon loss through the sample container. The analyses are also compatible with over 800 γ-ray spectrometric results previously measured on Ge(Li) detectors at SURRC for aerial survey calibration. The sample analyses are also traceable through cross comparison to BNFL results from cores collected in the Ribble [18].

3. RESULTS AND DISCUSSION

The results of the overall radiometric maps produced during the first stage of the project are presented in the following section for each nuclide, and the main features noted. Thereafter the results from samples and ground to air comparisons are presented in sections 3.2 to 3.4. This demonstrates that the working calibration is capable of quantitative applicable to fallout mapping in the terrestrial environment where the majority of activity is close to the ground surface. The results from Wigton merse confirm the presence of pronounced subsurface activity maxima, consistent with the observations in previous studies at Caerlaverock, and in the Ribble. Section 3.5 presents a correction factor to account for source burial on the merse, and a series of detailed maps for the principle merse sites, corrected for source burial effects. Sections 3.6 and 3.7 present results from a carborne survey conducted to investigate the uranium series activity in the Wigton peninsula, and a specific examination of spectral records in the vicinity of the Dundrennan range. The relation between the results of this study and other relevant studies of the radiation environment of SW Scotland is discussed thereafter.

3.1 Radiometric Maps of Main Survey Area

The overall radiometric maps for ^{137}Cs, ^{40}K, ^{214}Bi, ^{208}Tl and gamma dose rate are presented in figures 3.1 to 3.5 respectively. They show clearly the distributions of each individual nuclide, and indicate the contribution which certain localised enhancements make to the overall gamma ray dose rate. These maps are identical to those produced, using the working calibration described in section 2, for the preliminary report in March 1993.

The ^{137}Cs map indicates the coastal and terrestrial spatial distributions of this nuclide in considerable detail. Levels of ^{137}Cs in the environment range from approximately 2 kBqm^{-2}, a level consistent with global weapons testing fallout, from 2-40 kBqm^{-2} on sites affected by peak deposition of fallout from the Chernobyl accident, and from 40 kBqm^{-2} to >200kBqm^{-2} on tide washed sites which have accumulated marine sediments from the Irish sea. All three levels are represented within the survey zone, in a manner consistent with the findings of previous aerial surveys in adjacent areas, and with ground based studies.

The terrestrial distribution of ^{137}Cs is attributed largely to the effects of the Chernobyl fallout, whose distribution is revealed in considerable detail. The main deposition in Dumfries and Galloway appears to have occurred between an area just east of the Nith, and Glenluce. Levels on the Mull of Galloway are lower, the majority of ^{137}Cs being consistent with global weapons testing fallout levels. The northern limit of Chernobyl deposition has not yet been defined by aerial survey, and there may be grounds for considering extension of the northern, and particularly eastern limits of the inland survey zone to this end. Within the survey the deposition pattern is complex, including both upland and lowland components.

Comparison between these maps and published 1990 Scottish Office deposition estimates[28] is interesting. While many of the features observed in this survey are present in the 1990 maps, there is considerably more spatial detail here, for obvious reasons, and some notable differences. The general level of Chernobyl activity inferred from these maps is highly consistent with published levels for the area. The differences are more subtle, and reflect the deposition conditions, prevailing wind directions, and the considerable amount of additional information provided by the aerial survey results compared with the relatively small number of environmental samples examined in earlier ground-based work. In addition to extra evidence for fragmented deposition at the 5-10 km scale, reflected by the presence of some 10 or more identifiable deposition peak areas, it is notable that the general orientation of the deposition plumes are further to the North than the generally NW direction assumed from meteorological data. This finding was also observed in the 1990 Ayrshire survey[14] where, although the main deposition in Arran was in the general area predicted from meteorological data, the plume direction was clearly aligned in a more northerly direction. The observation of a more northerly trajectory than previously supposed for the main Chernobyl plume, and the pattern of deposition in SW Scotland, could potentially resolve the contradiction between meteorological estimates and later measurements of Chernobyl activity in the Central Highlands. The original meteorological estimates published in 1988[27] predicted negligible levels of fallout in the Central Highlands, whereas aerial survey observations conducted in 1989[1] and ground based results published in 1990[28] demonstrated levels comparable with peak UK deposition in this area. The data presented here both add considerably to previous knowledge of the distribution of Chernobyl activity in Scotland, and serve as a baseline against which any future changes can be measured.

The survey results and maps have also identified a number of terrestrial sites, mainly on merse (salt marsh), which have accumulated appreciable activity from past discharges of low level radioactivity from Sellafield. This finding is consistent with the results of previous SURRC aerial surveys in coastal and estuarine environments around the Irish Sea, which have identified contaminated salt marsh sites in West Cumbria, North Wales, the Ribble, the inner Solway and, at lower concentrations, in the Firth of Clyde[12,13,14,16,17,18]. Contamination of sediments in the Irish Sea basin by past marine discharges from Sellafield is well established[19,20,21,22,23,24,25,26], as is the transfer of activity to sites where such sediments accumulate. The importance of this latest survey, conducted at 500m resolution, is that it provides systematic coverage of the entire merse system for the first time, and is therefore expected to have identified all the major terrestrial sites which have received contaminated marine sediments. Small scale features will potentially be underestimated, and the edges of the sites could be defined with greater detail by local surveys at low altitude, as shown in West Cumbria in 1988, and in the Ribble in 1992. A list of the main merse sites identified with OS grid references is shown in table 3.1. This list includes a number of locations which are not monitored routinely under existing Scottish Office arrangements. It would, as suggested in section 4, therefore be prudent to extend routine monitoring to some of these locations, and to ensure that their potential significance is considered in radiological assessments. Some of these locations, for example Kirkconnel and Wigtown merses are extensive (several km long, up to 1 km wide) and fall within SSI's. Furthermore they are potential key sites for studying future deposition trends.

As noted in section 2, there are reasons to expect the working calibration to underestimate the activity inventories of buried sources, such as those encountered on merse sites. This is examined in more detail in section 3.2, and a set of more detailed maps for these areas is presented in section 3.5.2. It is clear that the aerial survey provides an extremely effective method for identifying contaminated areas, and directing ground based examinations to them.

Table 3.1 Locations of main merse deposits.

Site	Location	OS Grid Reference
1	Kelton Bank Merse	NX 983 714
2	Kirkconnel Merse*	NX 985 685
3	Carse Bay Merse	NX 984 602
4	Needles Eye	NX 916 560
5	Kirkennan	NX 827 578
6	North & South Glen	NX 830 560
7	Orchardton Bay	NX 817 535
8	Craigs Hall	NX 806 518
9	Sandside	NX 680 497
10	Kirkudbright	NX 675 505
11	Tongland	NX 687 534
12	Fleet Bay	NX 579 559
13	Gatehouse of Fleet	NX 597 559
14	Carseminnoch	NX 446 628
15	Carsewalloch	NX 459 610
16	Wigtown Bay Merse*	NX 441 555
17	Piltanton Burn	NX 168 564

Naturally occurring nuclides reflect the underlying geological and geomorphological contexts of the landscape. Granite intrusions are readily visible in ^{40}K, ^{214}Bi and ^{208}Tl, most notably at Cairnsmore of Fleet, the Loch Doon Granodiorite, Glencairn of Carsphairn, the Dalbeattie granite and Criffel Pluton. The small granite outcrop at the SW tip of the Mull of Galloway can also be seen. The rest of the area is dominated by Ordovician and Silurian geosynclinal sediments, which were subsequently folded along a NE axis during the Caledonian orogeny. During the lower palaeozoic, rocks were metamorphosed and intruded by the granodiorites. Metalliferous mineralisation has been identified, concentrated around the Criffel pluton, including a number of small scale uranium veins, whose presence can be seen on the ^{214}Bi map. The general reduction in natural signal levels from all nuclides which can be observed in inland areas, particularly to the NW of areas B and C, is attributed largely to the presence of a greater proportion of organic rich, and peaty overburden associated with the poorer and marginal agricultural lands.

A number of areas of enhanced ^{214}Bi, which may reflect radon potential, were noted. In one case on the west of the Wigtown peninsular a strong Rn associated ^{214}Bi signal was observed. This was proven to have been a transient effect associated with the weather conditions prevailing during the survey, and was later investigated during a carborne survey in September 1993.

Examination of the overall gamma ray dose rate maps shows that natural sources are responsible for the majority of environmental radiation exposure. However it is clear that external dose rates on merse sites in particular are for the main part controlled by the presence of ^{137}Cs derived from marine sources. The spatial extent of such merse deposits, while representing a small proportion of the landscape, both comparable in extent and dose rate with several notable granite intrusions, is nonetheless greater than has been described on the basis from previous ground based studies [20-26]. This is most probably a reflection of the impact of a total survey method on a problem which has previously been studies using sparse ground based sampling methods supported by topographic information on tidal limits. The radiological significance of features of this sort is dependent on occupancy factors. It is clear that the areas affected include locations which might be expected to attract unusual patterns of occupancy and sensitive ecologies. It would be prudent therefore to review radiological assessments in the light of this most recent work to ensure that such factors are taken fully into account. The future trends are also of interest, since although the reduced Sellafield discharges may well have had an early effect on fission product inventories derived from direct soluble phase transport, the behaviour of particulate activity is less clear, and deserves continued attention.

As noted in previous aerial survey reports[17,18] the dose rates inferred from salt marsh contexts may be underestimated due to the combination of geometrical effects from small scale sources, and to the use of a calibration factor for dose rate conversion derived from natural radiation fields. It has been shown that aerial survey dose rate estimates in the salt marshes of the Ribble are broadly consistent with routine ground based measurements[44], however there is scope for further investigation of dose rate measurement methods using radiometric data.

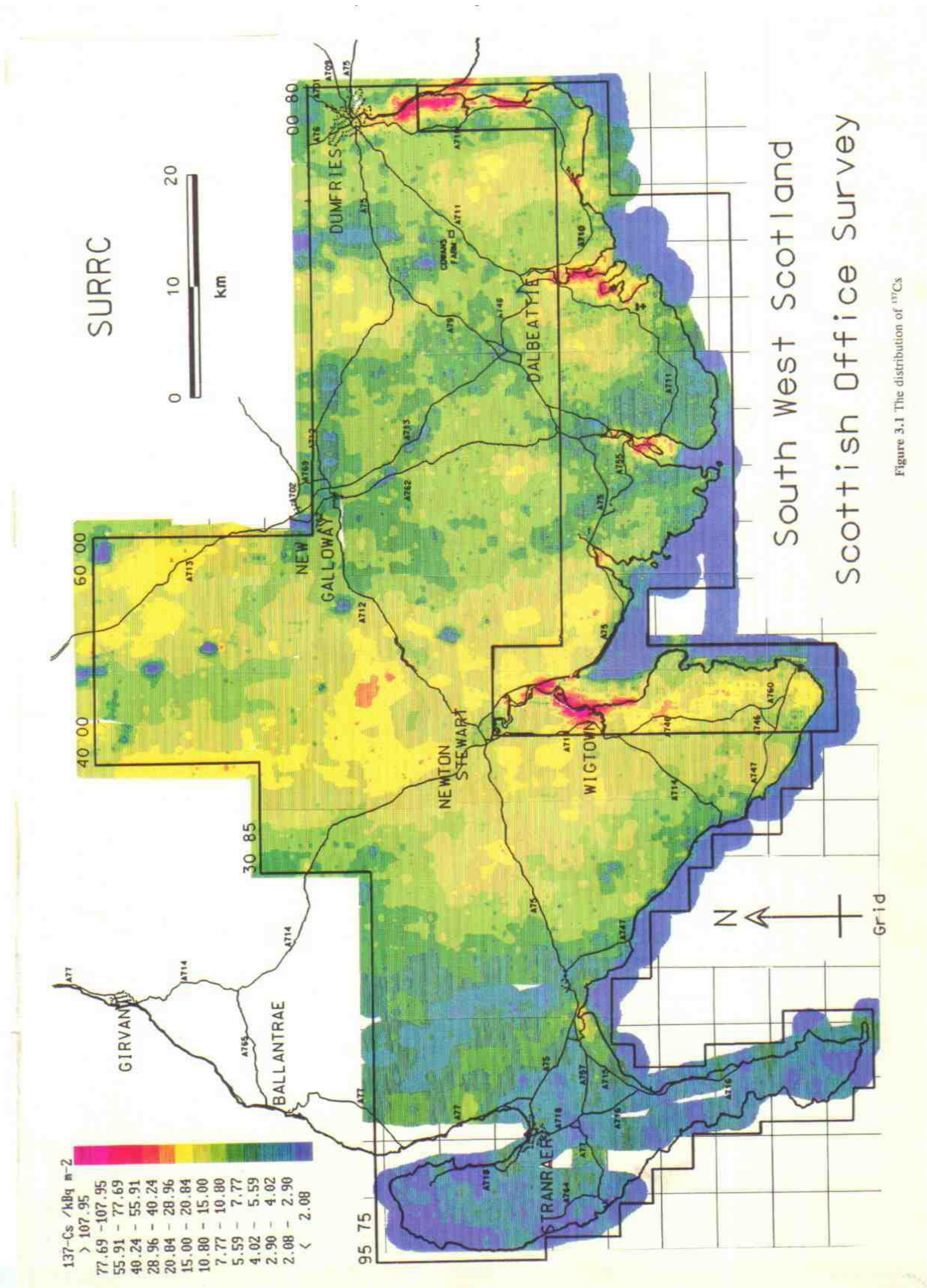


Figure 3.1 The distribution of ^{137}Cs

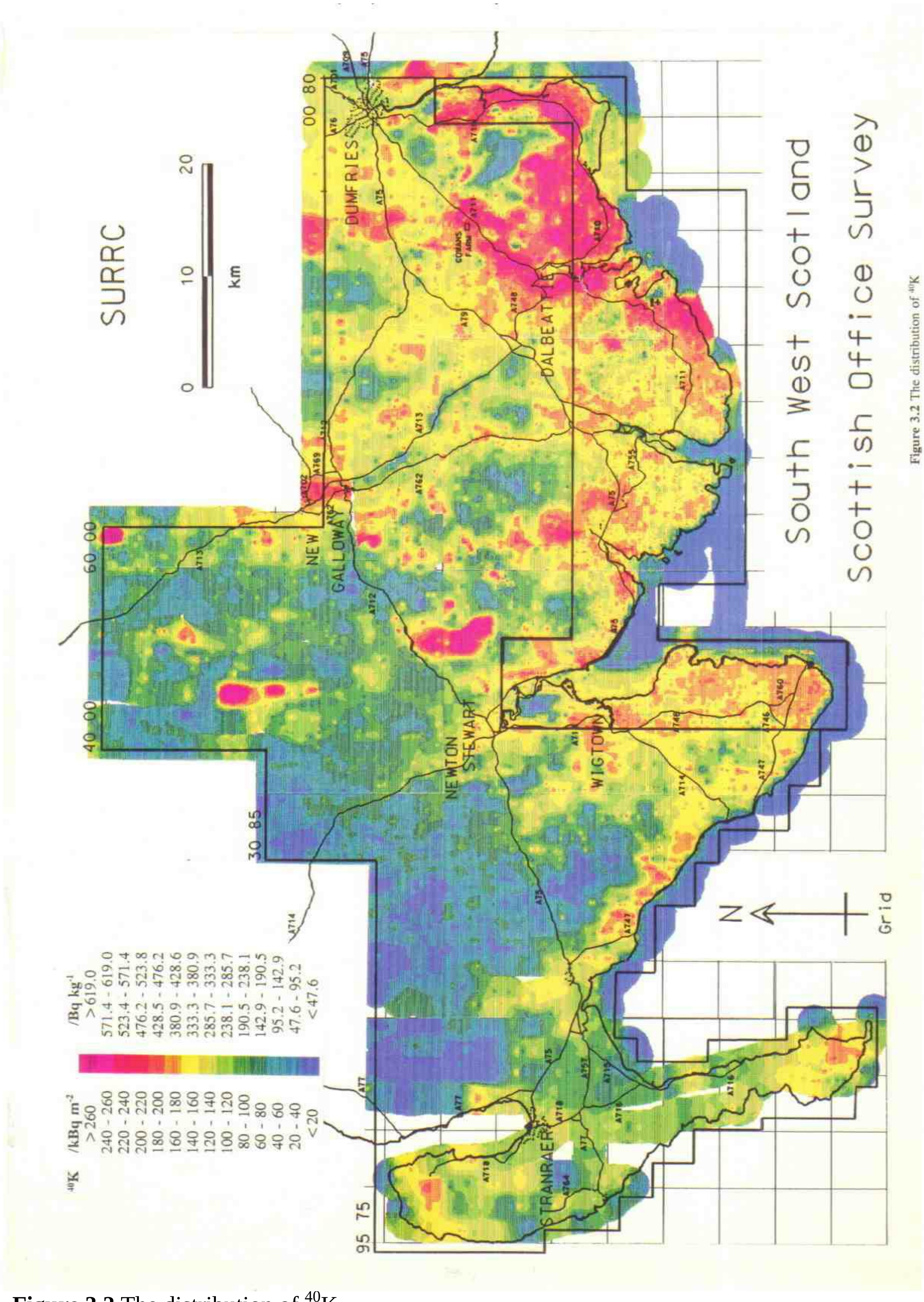


Figure 3.2 The distribution of ^{40}K

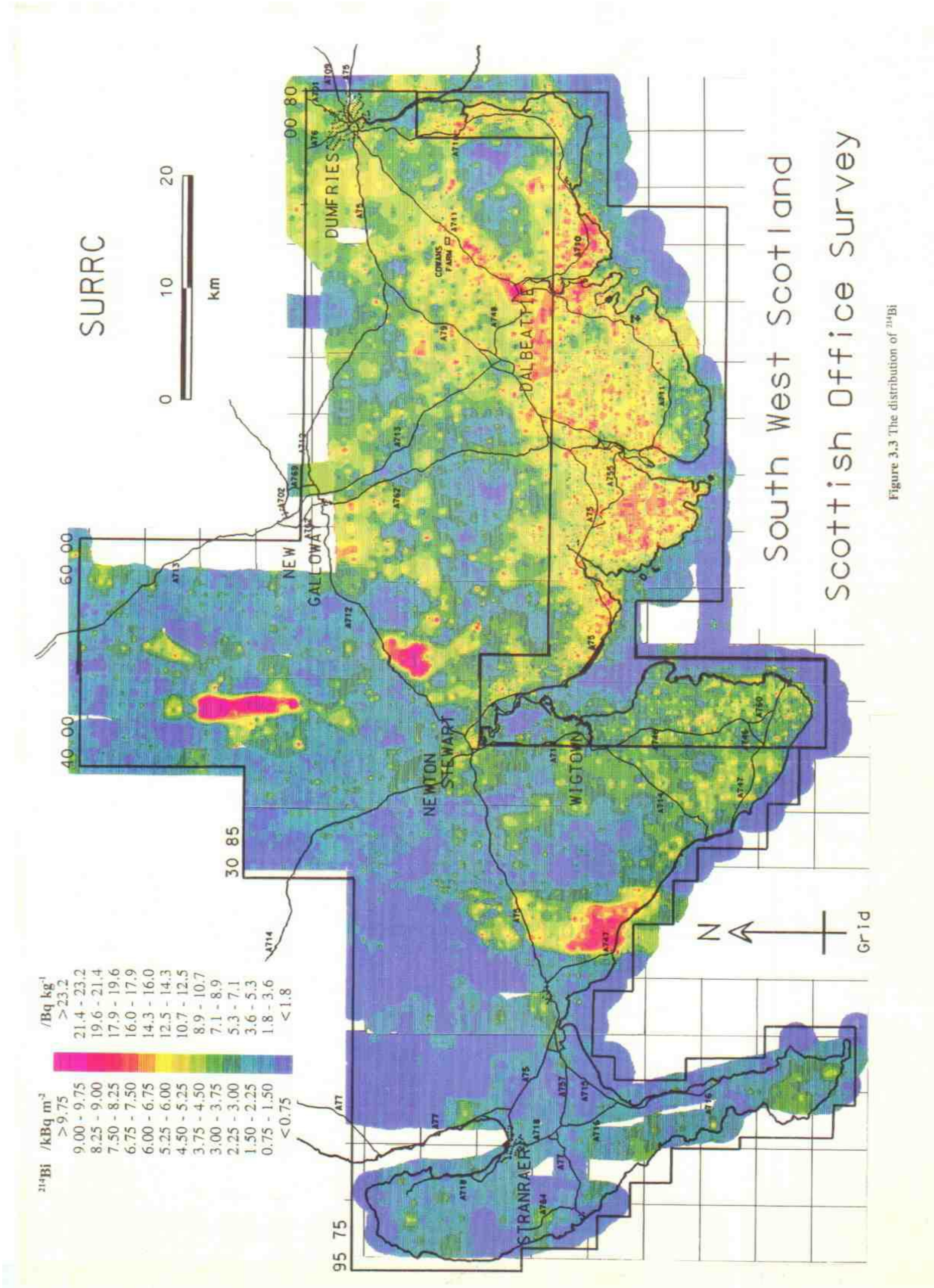


Figure 3.3 The distribution of ^{214}Bi

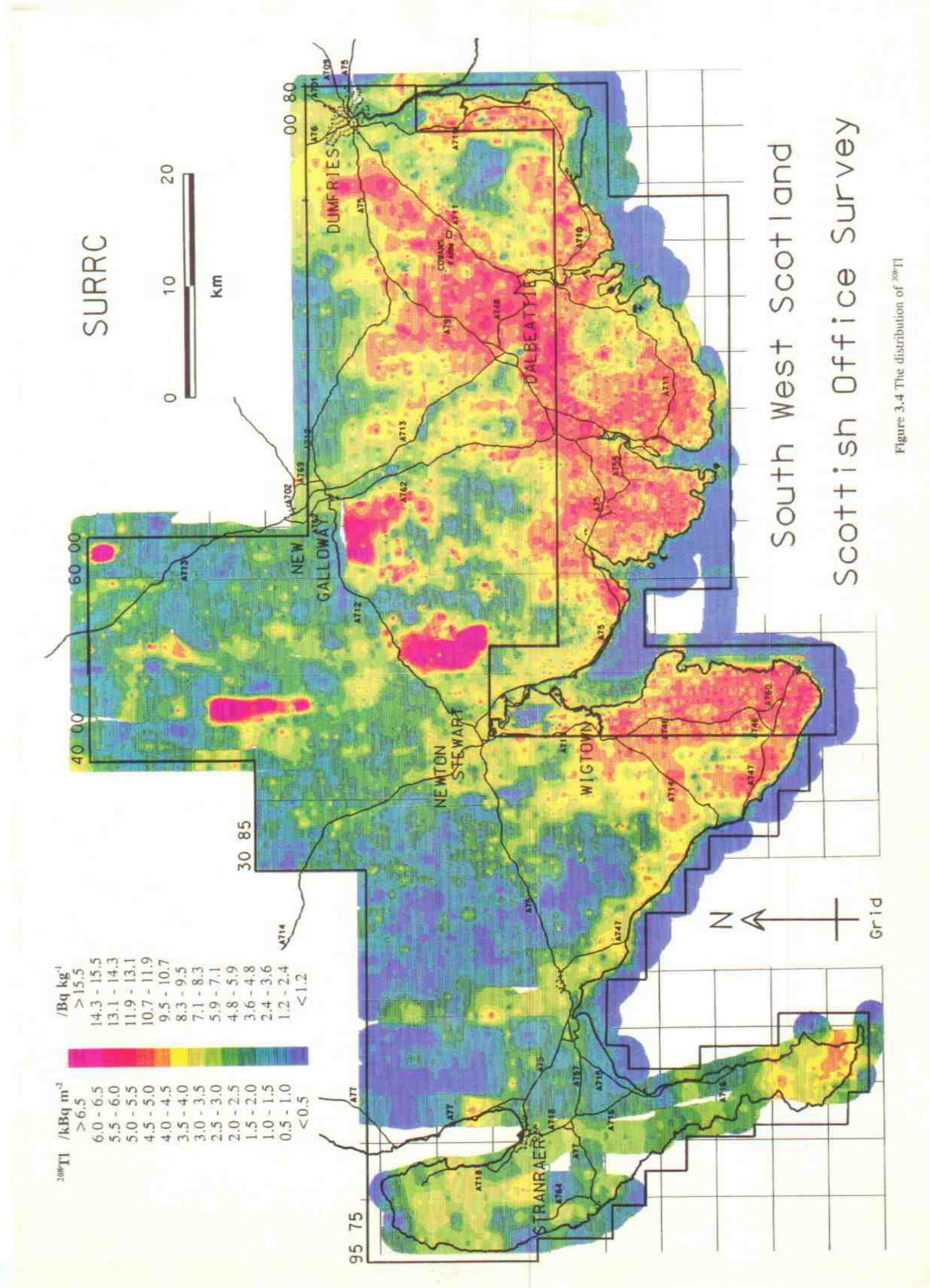


Figure 3.4 The distribution of ^{208}Tl

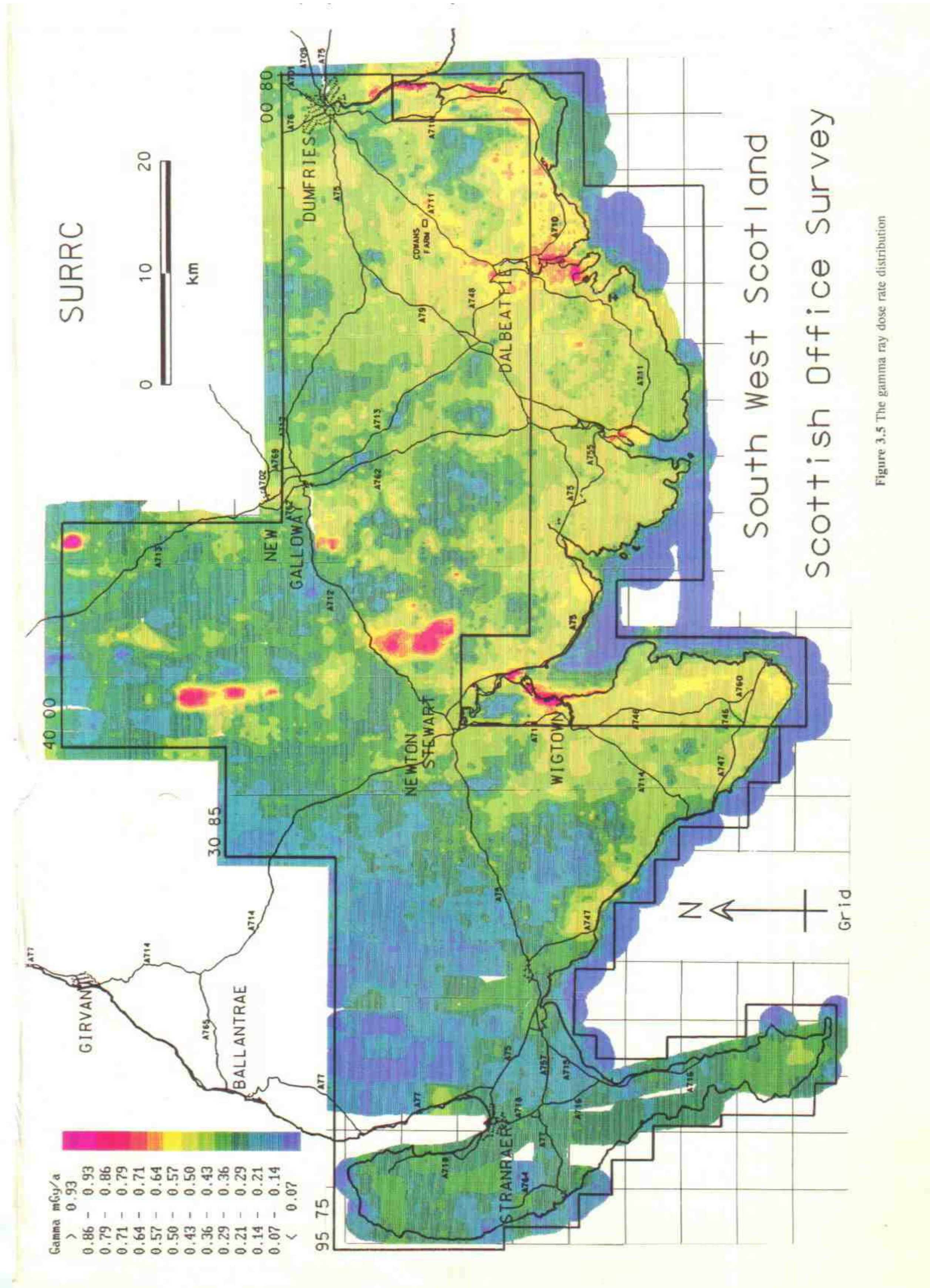


Figure 3.5 The gamma ray dose rate distribution

3.2 Ground to Air Comparisons Inland

The ground to air comparisons were made with in-situ spectrometric and soil sample measurements. The in-situ calibration was tied in to the aerial survey calibration by spatially matching the calibrated activity estimates at Caerlaverock with the aerial survey estimates.

As explained in section 2 our expectation was that the working calibration should reconstruct recent deposition of ^{137}Cs on Chernobyl sites. However, it was considered to be important to examine the extent of variation between activity estimates on inland sites based on aerial survey, in-situ gamma spectrometry and analysis of cores.

3.2.1 Longbridgemuir Calibration Site

The Longbridgemuir site, discovered during the Chapelcross survey[17] represents an area of flat basin valley peat which has an appreciable Chernobyl signature. In addition the peat cover attenuates any underlying geological features. The site is therefore relatively unique as it provides an almost pure ^{137}Cs and ^{134}Cs signal.

Table 3.2 summarises the spatially weighted mean ^{137}Cs inventory estimation for a detector at 100 m altitude.

Figure 3.7 shows ^{137}Cs source distribution characteristics in the Longbridgemuir site. Here a non linear profile is observed due to ^{137}Cs being bound on to organic particles which with the movement of water and additional diffusion processes leads to a decrease in activity with depth. The depth of ^{137}Cs penetration is thus a factor controlled by soil type and hydrology. Figure 3.7 illustrates variability across the site. Note also that the soil is highly organic, resulting in low density which effectively reduces the mass depth distribution.

Table 3.2 Longbridgemuir Calibration Site: ^{137}Cs Bq m^{-2}

^{137}Cs: 16 litre detector at 100m altitude					
Radius /m	% weighting	% Cumulative weighting	Activity /Bq m^{-2}	Std. Dev.	Std. Er.
2	1	1	9972	3325	1357
8	2	3	7821	1875	765
32	32	35	9622	2427	991
128	65	100	9681	2128	869
		Mean	9628	2231	869

Table 3.3 depicts the comparison between the spatially weighted soil sample inventories with aerial survey derived measurements, and a single in-situ measurement. There is a good agreement between the aerial survey derived estimates and core results. However, there is less satisfactory agreement with in-situ spectroscopy, which may reflect the spatial variability

of the site, as well as changes in source depth distribution.

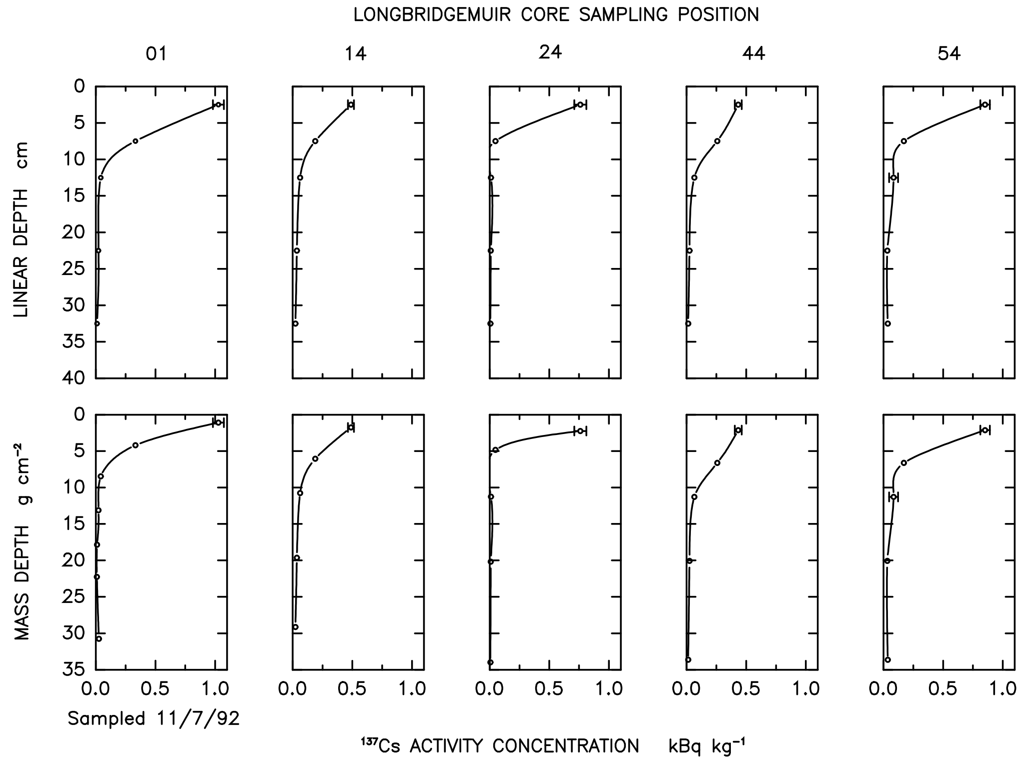


Figure 3.7 Illustrating the change in source depth characteristics across Longbridgemuir Calibration Site

Table 3.3 ^{137}Cs ground to air comparisons at the calibration sites

Sites	Soil Type	Activity kBq m^{-2}		
		Aerial	In-situ	Soil Samples
Longbridge-muir Farm	Basin and Valley Peats	12.0 ± 2.0	16.47 ± 0.5**	9.6 ± 2.2*

* Mean value spatially weighted for field of view at 100 m altitude. ** Spot measurement at centre of sampling area.

3.2.2 Inland Transect

In order to examine calibration parameters, assess radionuclide distribution and variation within different soil types across the inland region comprising area "C", a set of core samples was collected at regular intervals along a transect from Dumfries to Stranraer. The field work was arranged by permission of The Forestry Commission and local land owners.

The transect running East-West across Dumfries and Galloway Region is illustrated in figure 2.3 and encompasses both upland and lowland sites thereby also crossing a wide range of soil types from upland low density peats to lowland clay rich and sandy soils. Core samples taken at these sites were processed in an identical manner to those previously described. A dried sub-sample of each was prepared in 150cm^3 standard geometry for high resolution counting purposes. Each sample was counted for 50,000s. The radionuclide inventory was determined and cross compared with calibrated aerial survey measurements made from flight lines nearest to each ground sampling point. The individual core results are listed in Appendix B.

The results from the ground to air comparisons are summarised in table 3.4. The results demonstrate a high level of compatibility between ground soil cores with in-situ and in particular aerial survey results. Residual variation between the comparable measurements can be explained by the problems of spatial variability and changes in the source mass depth characteristics (owing to variation in soil density and depth of ^{137}Cs distribution within the soil). Table 3.4 illustrates that some upland sites (e.g. Crofts) are likely to have a low mean mass depth of source burial leading to some overestimation of ground activity, whilst some high density soils (e.g. High Boreland) with a higher mean mass depth will lead to some underestimation of ground activity. However, these results clearly confirm that the working calibration used for aerial survey, accounts for a variety of environments. The influence of source burial is likely to have a greater effect on detector response characteristics with field based detectors than airborne detectors due to the wider angular response of the former.

Table 3.4 ^{137}Cs ground to air comparison. Transect East - West

Sites	Soil Type	Activity kBq m^{-2}		
		Aerial	In-situ	Soil Samples
Nutholm	Clay	4 ± 1	4.28 ± 0.22	5.66 ± 0.51
Ingleston	Clay	11.5 ± 2	13.25 ± 0.4	14.6 ± 1.1
Crofts	Peat/min.-clay	19 ± 2.5	20 ± 1.4	11.6 ± 0.8
Shaw Fell	Clay/stony	12.95 ± 2	10.3 ± 1.2	7.95 ± 0.59
Ben Breck	Upland Peat	6.8 ± 1	---	8.34 ± 0.56
Curlywee	Upland Peat	14.8 ± 2	18.9 ± 6.3	13.86 ± 0.70
Drannandow	Clay/min.	17.1 ± 2.5	15.9 ± 6.3	15.8 ± 1.1
Barford Fell	Peat	12.4 ± 2	16.3 ± 2	16.15 ± 1.18
Artfield	Peat	8.55 ± 1.5	8 ± 1	5.43 ± 0.22
Dunragit	Clay/Peat - variable	6.04 ± 1.5	9.4 ± 0.5	6.9 ± 0.50
High Boreland	Sandy	2.75 ± 1	3.7 ± 0.2	5.03 ± 0.41

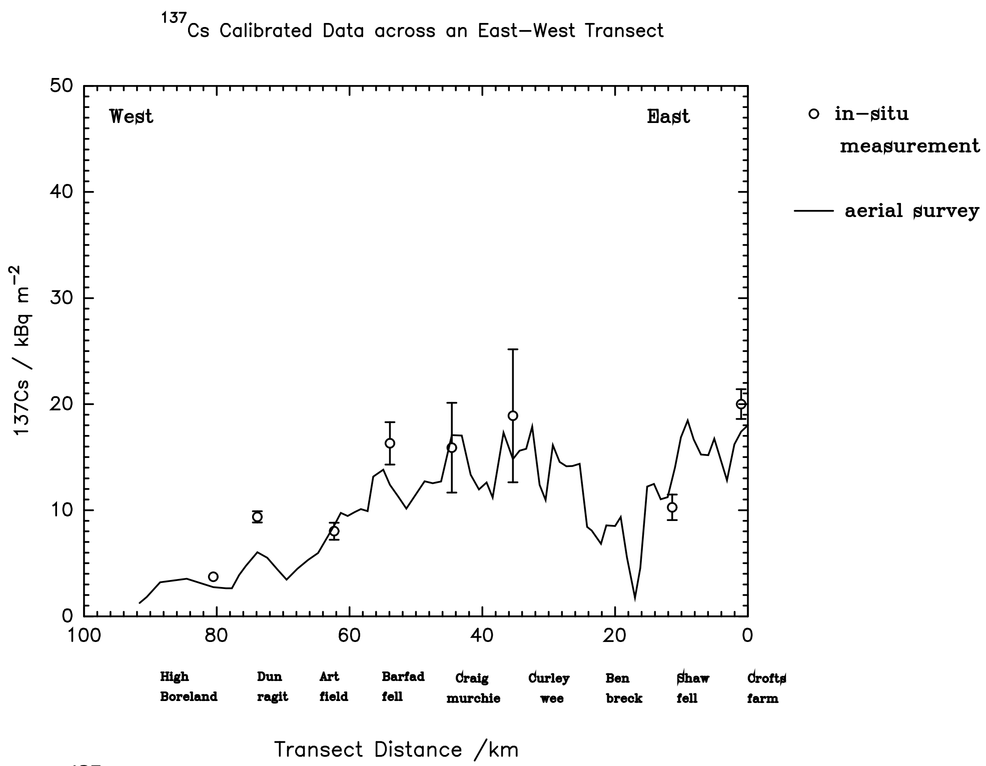


Figure 3.8 ^{137}Cs Transect across SW Scotland

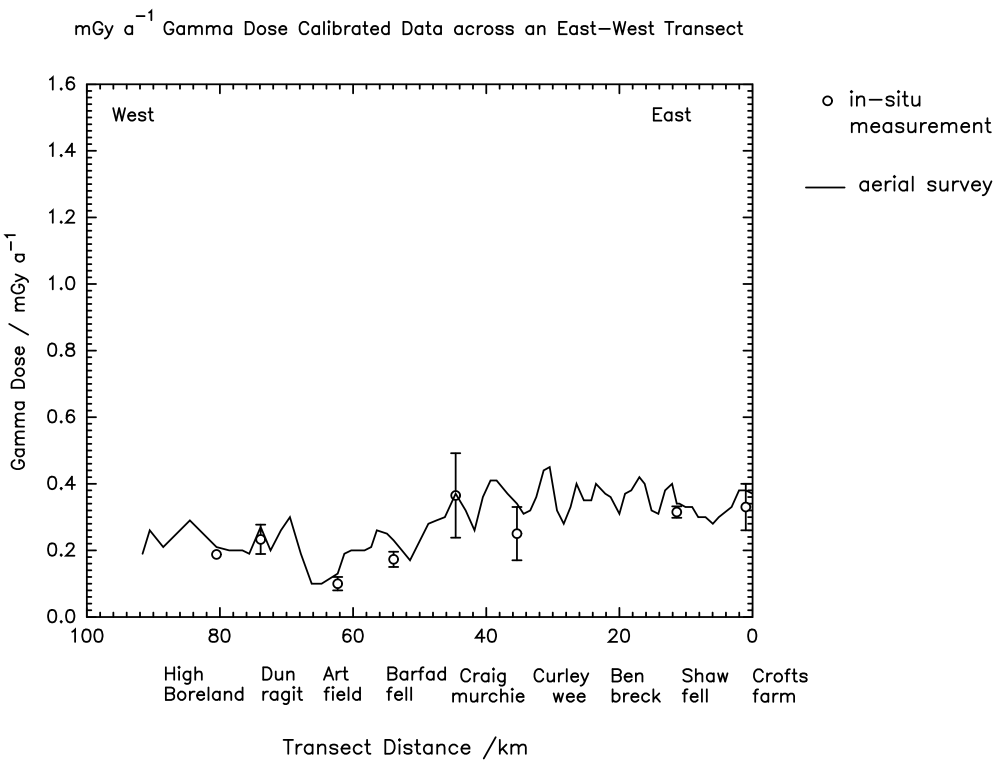


Figure 3.9 Gamma Dose Rate Across SW Scotland

In addition the data clearly illustrates the magnitude of the Chernobyl plume which stretches across the south west of Scotland. This corroborates the spatial distribution indicated by the aerial survey map (figure 3.1) and illustrates two ridges of enhanced Chernobyl activity separated by a moderate area and edged by low areas of ^{137}Cs activity typical of weapons testing fallout (figure 3.8). The cross matching estimates are shown in figures 3.8 and 3.9 for ^{137}Cs inventory and total gamma dose rate respectively.

Table 3.5 shows where the "spot" in-situ measurements were made. Here, the ground to air comparisons are highly concordant.

Table 3.5 Spot Measurement - In-situ to Air Comparison Sites

Site	Grid Ref.	Soil Type (approx)	Activity kBq m^{-2}	
			Aerial	In-situ
Gillespie	NX 247 524	Clay	3.9	3.38
Port William	NX 342 439	Clay	7.01	11.5
Larroch	NX 378 410	Clay	15.9	18.4
Chaple Oughton	NX 446 420	Clay	19.7	26.0
Sorbie	NX 450 474	Clay	25.3	25.9
Deer Park	NX 520 732	Peat	15.6	22.7

From this data set on inland sites, it can therefore be concluded that the working calibration, adopted during fieldwork and used to prepare preliminary maps (traceable to all previous SURRC radiometric surveys of Chernobyl affected contexts), produces a satisfactory estimate of the spatially averaged activity per unit area of ^{137}Cs across a wide range of coastal and upland environment. The aerial survey results are compatible with both ground based in-situ estimates, and importantly with the results from conventional core samples analysed by high resolution gamma spectrometry. There is little evidence for systematic over- or under-estimation of inventories by any of these three methods. Moreover the precision of absolute activity estimates is constrained by environmental rather than analytical conditions and therefore aerial radiometrics are equally accurate for practical purposes than any other approach.

3.3 Results of Laboratory Analysis of Merse Calibration Site Cores

3.3.1 Wigtown Merse

Appendix B summarises the mean radionuclide activity inventories per unit area (kBq m^{-2}) and in terms of activity per unit weight (Bq kg^{-1}) for their ranges within each hexagonal shell. Individual core results can be found in Appendix C.

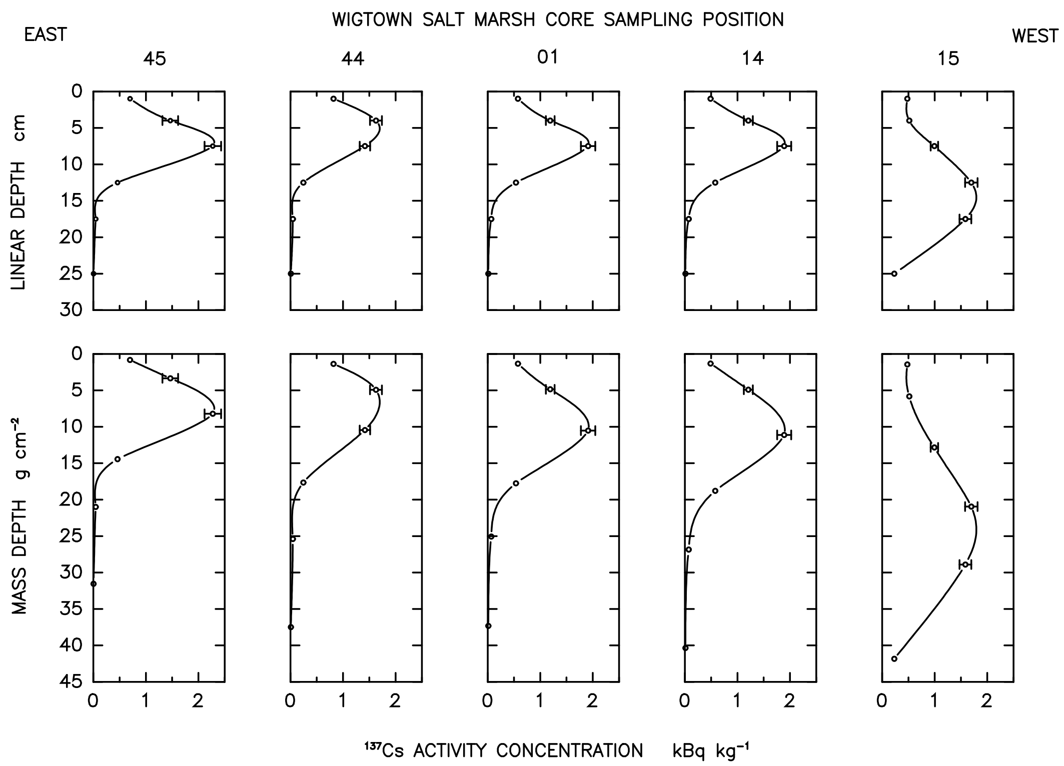


Figure 3.9 Illustrating the change in source depth characteristics across Wigtown merse

Figure 3.9 shows the change in ^{137}Cs source depth characteristics across the Wigtown Bay Merse. The cores are spaced 128 m apart and are orientated east-west. The observation of pronounced subsurface maxima in the salt marsh environment is consistent with investigations made elsewhere [17,32,36] in similar contexts. It contrasts with the essentially uniform profiles observed from well mixed marine sediments, for example at Palnackie Harbour[41,42,43], and may reflect the variation with time in the concentrations of radionuclides in the suspended sediments which form the source of the deposits. This model, which does not allow for post depositional activity migration, would suggest that the reduction of Sellafield discharges from 1980-85 has already produced a reduction of activity deposition rates to the salt marsh, and associated reductions in dose rate. This is clearly a matter of some interest and importance for observing and predicting future trends. The main consideration here however relates to the impact on calibration of aerial and in-situ measurements. When quantifying photon fluence rates, the source depth distributions must take into consideration soil/sediment density. Thus linear depth becomes mass depth (g cm^{-2}) as shown in figure 3.9. The mean mass depth describes the mass depth of source burial, and as illustrated, increases towards the near shore environment. Hence source burial in the environment has considerable implications on detector response. The mean inventory estimates from each shell are weighted appropriately to match the spatial averaging of a 16 litre NaI(Tl) detector at 100 m altitude to calculate the mean inventory measured by the detector (table 3.6 for ^{137}Cs and Appendix B).

Table 3.6 Wigtown Bay calibration site: ^{137}Cs Bq m^{-2}

^{137}Cs: 16 litre detector at 100m altitude					
Radius /m	% weighting	% Cumulative weighting	Activity /kBq m^{-2}	Std. Dev.	Std. Er.
2	1	1	145.788	13.786	5.628
8	2	3	164.921	41.622	16.992
32	32	35	133.091	29.357	11.985
128	45	80	160.244	19.637	8.017
256	20	100	204.961	68.271	27.872
		Mean	160.447	32.855	13.413

3.3.2 Caerlaverock National Nature Reserve

Table 3.7 shows the results of the spatially averaged mean activity levels for the Caerlaverock Calibration site [17,32].

Table 3.7 Caerlaverock Calibration Site: ^{137}Cs Bq m^{-2}

^{137}Cs: 16 litre detector at 100m altitude					
Radius /m	% weighting	% Cumulative weighting	Activity /Bq m^{-2}	Std. Dev.	Std. Er.
2	1	1	84039	5189	2118
8	2	3	83376	7515	3068
32	32	35	83260	7140	2915
128	45	80	78754	33594	13715
256	20	100	39375	19907	8127
		Mean	72465	21586	8812

Since the Chapelcross survey in 1992 [17], it has been realised that the outer shell of the hexagon contributes less than originally believed to the response at 100m altitude, but the other altitude predictions remain the same.

3.3.3 Comparison between Aerial, In-situ and Core Derived Estimates of ^{137}Cs on Merse Sites.

As explained in section 2, the working calibration is expected to underestimate the inventories observed in merse environments, as a result of shielding within the source. This can be corrected for, providing that the extent of self shielding is similar from merse to merse. Previous observations have confirmed that the extent of shielding at Warton Bank in the Ribble is similar to that observed at Caerlaverock. The results from Wigton merse also appear to be consistent with this general pattern. Therefore, although there is evidence for variation of source depth within each site, this represents a second order effect in comparison with the overall difference between calibration factors on terrestrial contexts, which, as shown in the preceding sections are capable of operating over a range of soil types and landscapes without introduction of gross errors. Similarly for the merse sites the present evidence supports the use of a single working calibration. There is further scope for the development of analytical methods which utilise information in the scattered gamma spectrum to quantify self shielding of environmental sources.

Table 3.8 shows the underestimation between soil sampling and aerial & in-situ measurements.

Table 3.8 ^{137}Cs ground to air comparisons at the calibration sites

Sites	Soil Type	Activity kBq m^{-2}		
		Aerial	In-situ	Soil Samples
Caerlaverock	Salt Marsh	39.0 ± 3.0	37.0 ± 5.0*	72.5 ± 8.8*
Wigtown	Salt Marsh	90.0 ± 5.0	80.0 ± 10*	160.4 ± 13.4*

* Mean value spatially weighted for field of view at 100 m altitude. ** Spot measurement at centre of sampling area.

As described in section 3.3.1, this can be explained entirely by the effects of source burial. This leads to the attenuation of the primary fluence and contribution to the build-up of scattered photons in the spectra.

3.4 Discussion of Core Results

For traceability, the detector calibrations were verified with soil sample standards used during the sample analysis of the Caerlaverock calibration site. These soils were traceable to IAEA standards as discussed in the Chapelcross report [17]. The calibration was also verified for density correction, determined from a hybrid suite of soils of varying densities, spiked with an Amersham multi-nuclide gamma spike (QCY-44 + ^{241}Am spike).

For quality assurance and rapid determination of detector performance characteristics, a hybrid standard was mixed from proportions of a well characterised Caerlaverock sample, and a blend of IAEA geological certified reference materials (IAEA: RGK-1, RGU-1, RGTh-1).

The results of the hybrid standard sample analysis are illustrated in table 3.9. The reproducibility of the anthropogenic and natural radionuclides is highly consistent. There is an overestimation of the ^{214}Bi estimates by about +30 %. This is explained by the emanation of ^{222}Rn (a parent of ^{214}Bi) from the sample container, particularly in the Caerlaverock sample used to verify the calibration. Although every effort was made to ensure containment and ^{222}Rn equilibration, observed in the consistency in the ^{214}Bi estimates, ultimate interpretation must take into consideration the likelihood that the escape of ^{222}Rn from the sample and may lead to variable ^{214}Bi estimates.

Table 3.9 Showing detector derived estimates of the IAEA hybrid standard (IAEA RGK-1, RGU-1, RGTh-1)

Detector/ Sample size cm^3	**Inventories - Bq kg^{-1}**					
	^{241}Am	**^{137}Cs**	**^{134}Cs**	**^{40}K**	**^{214}Bi**	**^{208}Tl**
Inventory	**78.02 ± 2.77**	**419.5 ± 4.0**	**--**	**770.4 ± 40.4**	**694.9 ± 34.8**	**166.8 ± 8.34**
GSP 1 150 cm^3	81.15 ± 12.98	413.5 ± 29.3	21.00 ± 1.78	800.3 ± 31.3	1035 ± 177	165.4 ± 22.9
GSP 1 30 cm^3	78.43 ± 3.93	427.8 ± 5.5	20.18 ± 5.96	894.2 ± 77.1	1022 ± 61.1	167.9 ± 9.96
GSP 2 150 cm^3	71.23 ± 10.56	415.4 ± 22.0	25.16 ± 2.50	840.3 ± 40.7	1005 ± 168	116.7 ± 12.5
GSP 2 30 cm^3	77.22 ± 5.29	415.3 ± 5.6	17.2 ± 8.91	762.6 ± 58.5	1024 ± 66.69	165.0 ± 11.22

3.5 Radiometrics Results from the Merse Environment

3.5.1 Correction for Source Burial Effects

The calibration parameters for ^{137}Cs, used for the preliminary preparation of maps showing radionuclide concentrations, have been determined over a number of previous aerial surveys and field sampling visits. Many of the calibration sites for these have been inland that show Chernobyl and weapons fallout activity. This form of activity initially deposits on the surface as a planar source, but through natural processes, becomes a decreasing gradient from the surface to depths of 0.3-0.4m. The assumption of an exponential depth profile is often not observed practically, but is used to simplify theoretical calculations. There is clear evidence that sources in merse environments are distributed in a complex manner and show pronounced sub-surface maxima. In these cases a modification of the calibration parameters is necessary to account for the change in γ-ray attenuation and scattering characteristics through the soil column. Therefore SW Scotland has been mapped according to inland calibration parameters found in Appendix A (leaving the spatially smaller, coastal features under-represented) and additionally portraying detailed, estuarine maps separately with the calibration shown below. Methods are being currently developed to correct automatically for radionuclide profiles, based upon the scattered component of measured spectra and observed during SURRC trial flights in March 1993.

Wigtown Merse

^{137}Cs:

y=b.e(ax)	x=altitude, y=stripped cps	
	$a=-9.4893 \times 10^{-3}$	$\pm 0.2063 \times 10^{-3}$
	$b=1.1920 \times 10^{3}$	± 1.0114

@100m: 461.5 cps
Calibration: 0.34767 kBq m^{-2} per cps

Note. Wigtown merse calibration is 1.7559 times inland calibration.

3.5.2 Detailed Maps

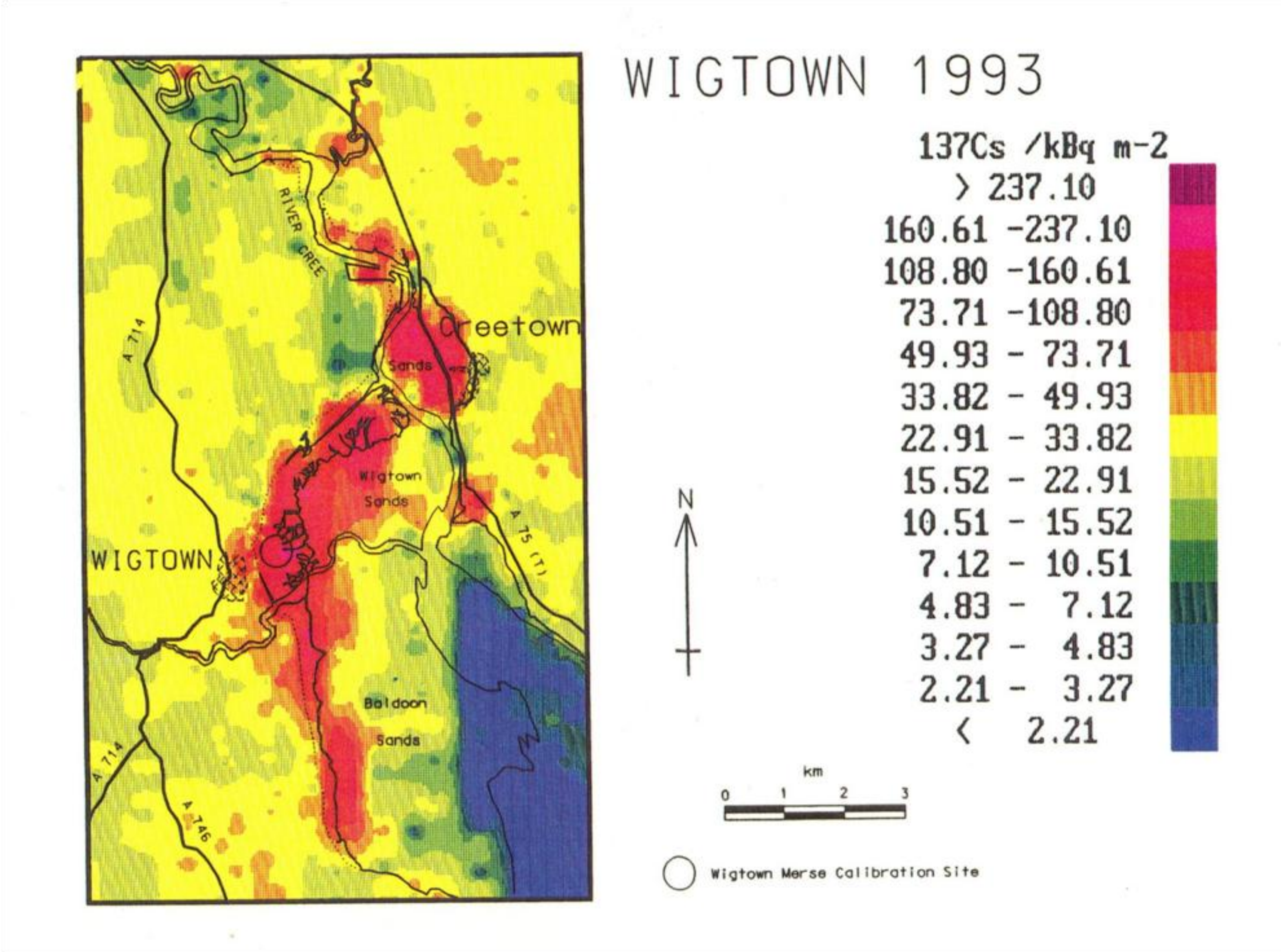

WIGTOWN 1993
137Cs /kBq m-2
> 237.10
160.61 -237.10
108.80 -160.61
73.71 -108.80
49.93 - 73.71
33.82 - 49.93
22.91 - 33.82
15.52 - 22.91
10.51 - 15.52
7.12 - 10.51
4.83 - 7.12
3.27 - 4.83
2.21 - 3.27
< 2.21
N
km
0 1 2 3
Wigtown Merse Calibration Site
Creetown
Sands
RIVER CREE
Wigtown
Sands
WIGTOWN
Baldoon
Sands
A 714
A 75 (T)
A 746

Figure 3.10

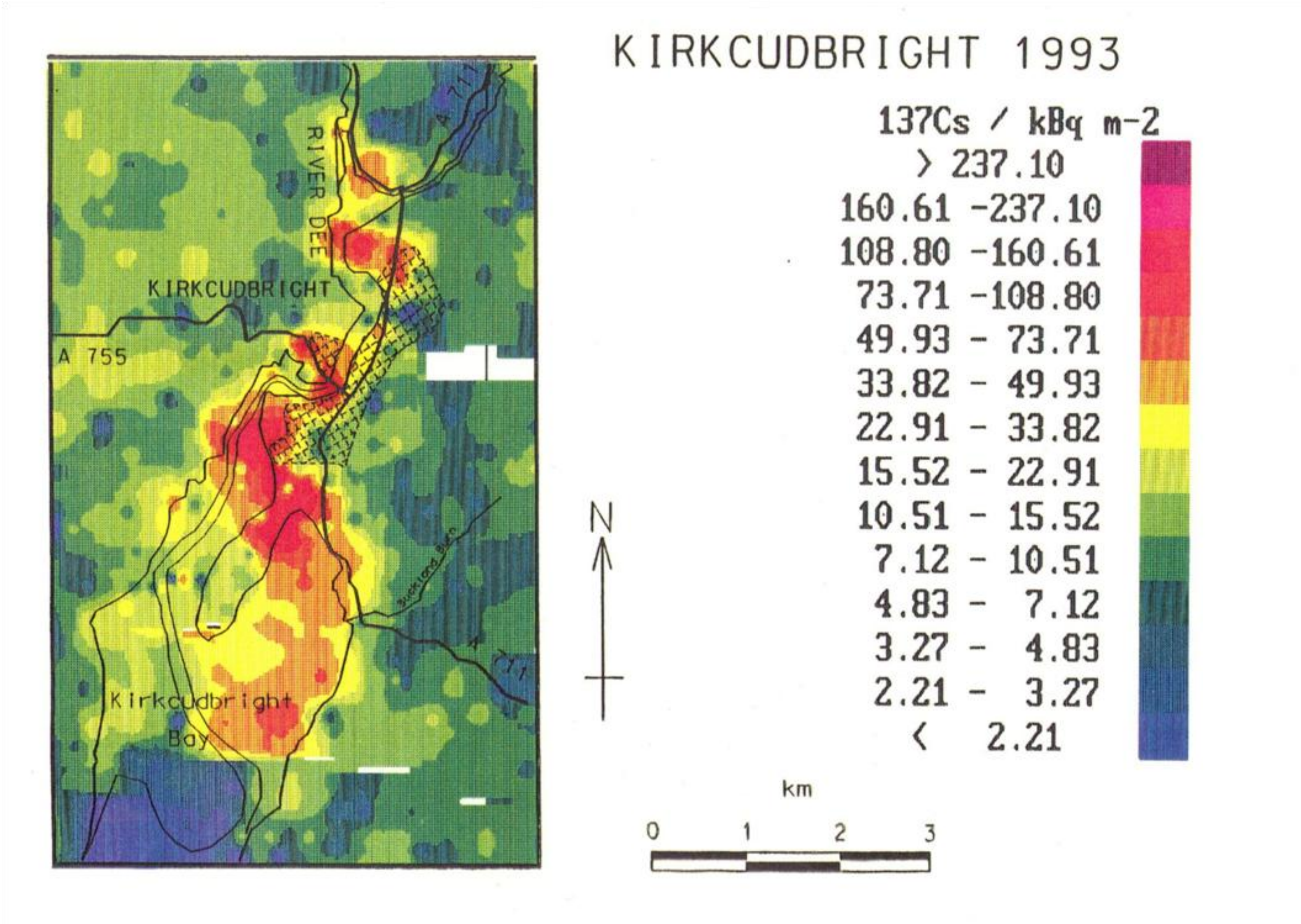

KIRKCUDBRIGHT 1993
137Cs / kBq m-2
> 237.10
160.61 -237.10
108.80 -160.61
73.71 -108.80
49.93 - 73.71
33.82 - 49.93
22.91 - 33.82
15.52 - 22.91
10.51 - 15.52
7.12 - 10.51
4.83 - 7.12
3.27 - 4.83
2.21 - 3.27
< 2.21
RIVER DEE
KIRKCUDBRIGHT
A 755
Kirkcudbright
Bay
N
km
0
1
2
3

Figure 3.11

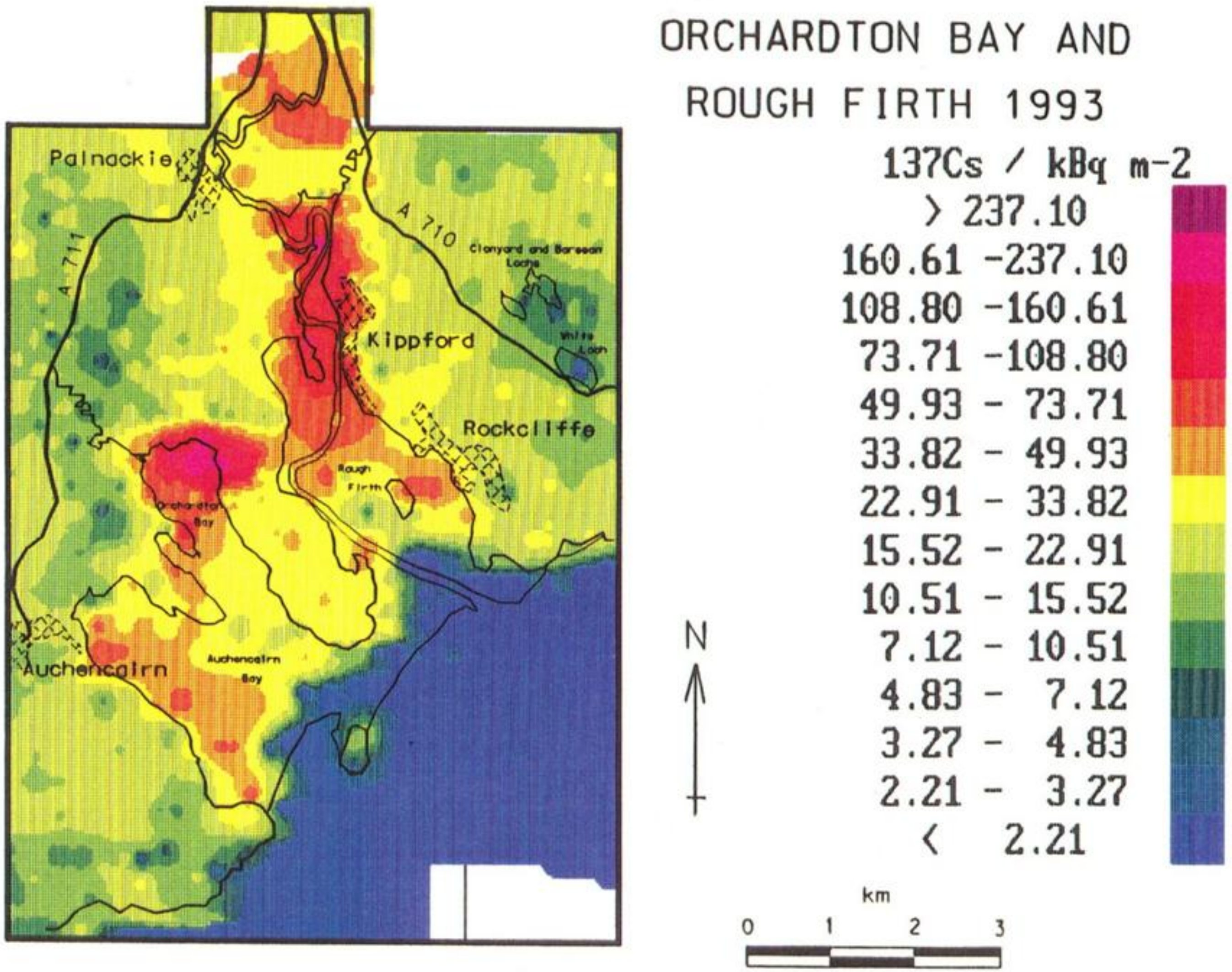
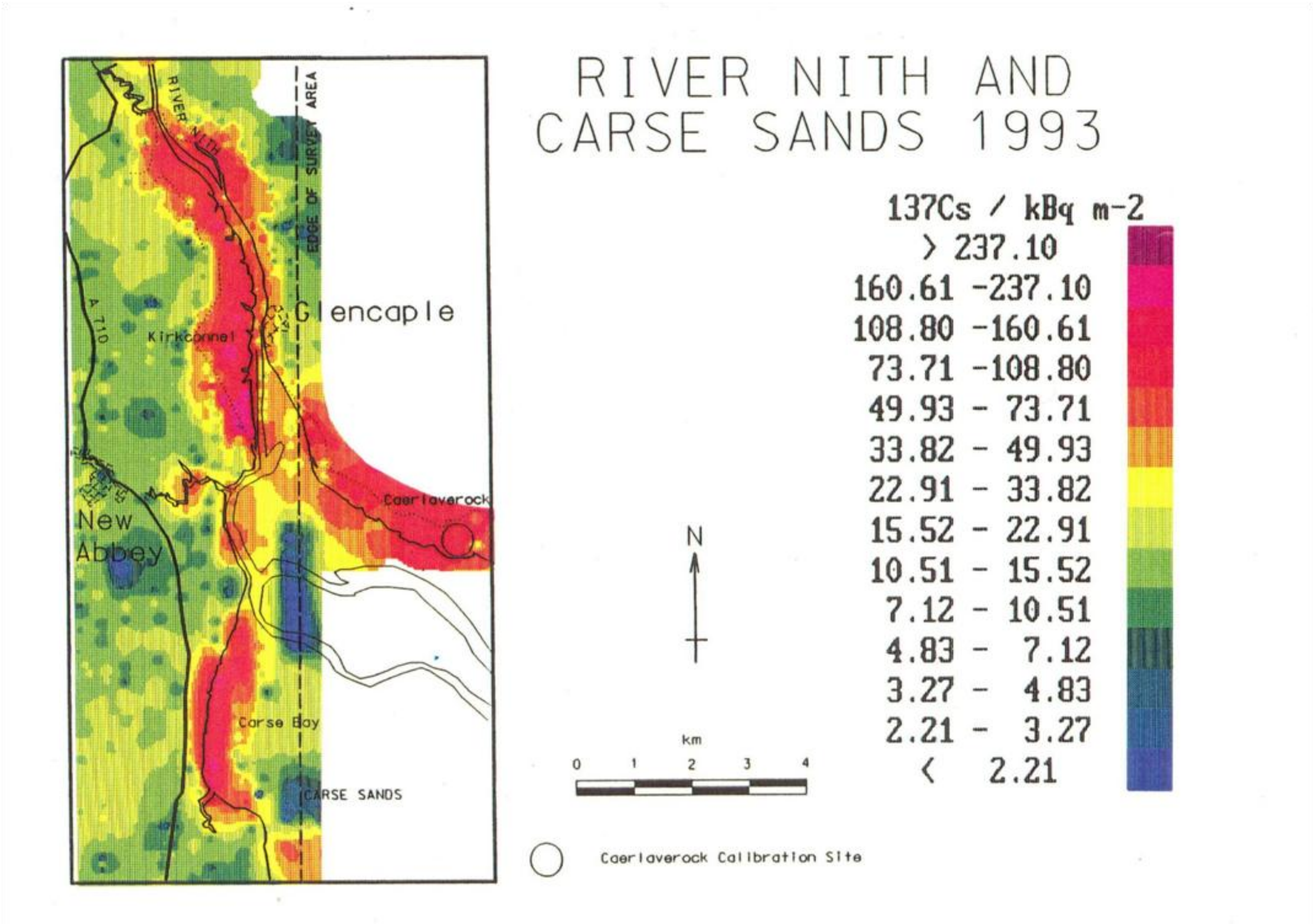

ORCHARDTON BAY AND
ROUGH FIRTH 1993
137Cs / kBq m-2
> 237.10
160.61 -237.10
108.80 -160.61
73.71 -108.80
49.93 - 73.71
33.82 - 49.93
22.91 - 33.82
15.52 - 22.91
10.51 - 15.52
7.12 - 10.51
4.83 - 7.12
3.27 - 4.83
2.21 - 3.27
< 2.21
Palnackie
A 711
A 710
Clonyard and Barean Lochs
Kippford
White Loch
Rockcliffe
Rough Firth
Orchardton Bay
Auchencairn
Auchencairn Bay
N
km
0
1
2
3

Figure 3.12



RIVER NITH AND
CARSE SANDS 1993
137Cs / kBq m-2
> 237.10
160.61 -237.10
108.80 -160.61
73.71 -108.80
49.93 - 73.71
33.82 - 49.93
22.91 - 33.82
15.52 - 22.91
10.51 - 15.52
7.12 - 10.51
4.83 - 7.12
3.27 - 4.83
2.21 - 3.27
< 2.21
RIVER NITH
EDGE OF SURVEY AREA
Glencaple
Kirkconnel
A 710
New
Abbey
Caerlaverock
Carse Bay
CARSE SANDS
N
km
0 1 2 3 4
Caerlaverock Calibration Site

Figure 3.13

3.6 Results of Carborne Survey: 7th September 1993

In order to investigate the ^{214}Bi anomaly near Glenluce, a carborne radiometric survey was carried out principally along the A747 (Glenluce, Whithorn, Sorbie) during 7th September 1993. In addition, measurements were recorded between New Galloway and Newton Stewart (A712), for comparison purposes. An 8 litre NaI(Tl) scintillation (25s counting period) and Ge semiconductor detector (60s) were operated in parallel from the rear of a slow moving hatch-back car (30-40 mph). Owing to the power requirements and duration of this survey, semiconductor detector operation had to be curtailed earlier than expected to enable scintillation detector measurements to be completed. Data processing of the road survey measurements are identical to that of aerial survey, except no calibration was attempted.
All spectral data were reduced to summary file format, backgrounds subtracted from corresponding windows (background cps used are those recorded from the 8 litre detector during the Sellafield survey 1990) and finally stripped to express data as relative true window count rates.

^{214}Bi count rates near Glenluce, and on the west side of the Wigton pensinsula do not show unusually high levels with respect to those further towards Whithorn (figure 3.14). This confirms the expectation during fieldwork that the ^{214}Bi anomaly near the Glen of Luce represents a temporary signal, due to localised concentration of radon daughters in the near coastal environment under still, foggy conditions encountered during the survey period. To some extent, variation of count rates may reflect the changing road composition and construction, and topographical effects of driving through built up areas or narrow gorges, etc. Other ^{214}Bi signals are believed to reflect genuine subsurface geology. The ability of radiometrics to monitor radon can be further enhanced by the use of "upward looking" detectors and enables radon in air to be measured directly. The additional use of semiconductor detectors also facilitates the direct measurement of ^{226}Ra (186 keV).

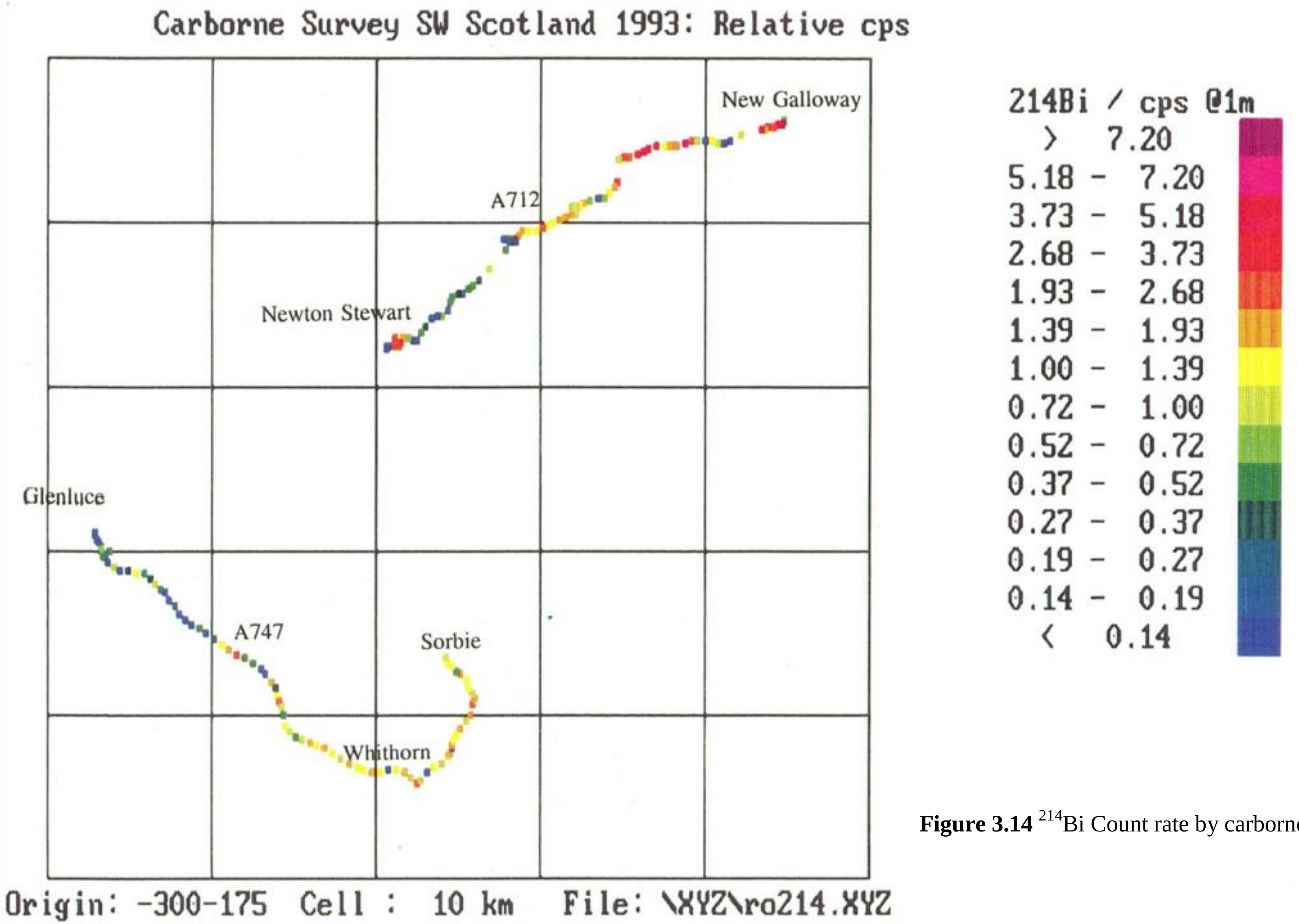


Figure 3.14 ^{214}Bi Count rate by carborne survey

3.7 Investigation of ^{234m}Pa near Kirkcudbright

For the purposes of identifying and potentially assessing the presence of depleted uranium, a component of military projectiles, full spectral files from the aerial survey data were re-integrated to isolate signals from ^{234m}Pa. This radionuclide is present in the decay series of ^{238}U, supported by ^{234}Th. Depleted uranium (deficient in ^{235}U) has characteristic γ-ray emissions, the most prominent at 1001 keV, which can lead to its unequivocal identification. Depleted uranium is usually produced as a byproduct of separation of ^{235}U in a diffusion plant or from re-processing of irradiated reactor fuel. In both cases uranium purification removes daughters below ^{234}U leaving a product whose gamma ray emission is dominated by the short lived ^{234}Th and ^{234m}Pa nuclides, which are able to recover equilibrium with the parent ^{238}U. Procedures to extract specific signals from ^{234m}Pa were developed and validated for the SURRC survey of Springfields and the Ribble Estuary commissioned by BNFL[18], these were followed to examine the data from area A for this nuclide.

3.7.1 Extraction Methodology

An extension of standard data processing procedures has been applied to dataset "A". The program *BNFAR32M* forms two summary files by reintegrating the original ".MCA" spectral files. Data processing parameters are held in files *GAM8.DAT* and *GAM9.DAT* which form ".SM1" and ".SM2" respectively. The spectral windows chosen were previously used with success in the Springfields and Ribble Estuary survey conducted in 1992, on behalf of BNF plc [18,33,34,35]. The format of ".SM1" and ".SM2" files is as follows:

.SM1

^{137}Cs:	95-130 ch.
^{234m}Pa:	160-180 ch.
^{40}K:	228-260 ch.
^{214}Bi:	275-307 ch.
^{208}Tl:	396-460 ch.
Total:	75-500 ch.

.SM2

^{228}Ac:	140-160 ch.
k1/k2 ratio	

The first stage of data processing was to restore ".MCA" survey files from storage tapes to hard disc. To determine background count rates in the above windows, a reintegration of the relevant background ".MCA" files was also required.

After the creation of ".NT1" and ".NT2" net files from the summaries ".SM1" and ".SM2" respectively, 6x6 matrix stripping was done using *GAM12.DAT*. A single stripped file was created ".SP1", which contained the following radionuclides (in order): ^{137}Cs, ^{234m}Pa, ^{40}K, ^{214}Bi, ^{208}Tl and ^{228}Ac. The stripping ratios for ^{234m}Pa and ^{228}Ac were defined by pure spectra measured at SURRC from a depleted uranium source, and simulated by Monte-Carlo calculation respectively. Calibration of the stripped file has been achieved using terrestrial calibration factors, with the exception of ^{234m}Pa and ^{228}Ac which remained as stripped cps normalised to 100m only (ie., calibration factor 1,0). Finally, "XYZ" files were created from the calibrated data set.

3.7.2 Findings

The entire region comprising survey area "A" has been investigated for the presence of excess ^{234m}Pa. Small varying count rates occur across the whole region, owing to authentic signals and residuals in the ^{234m}Pa window (figure 3.15). These are due to the presence of naturally occurring ^{234m}Pa in the uranium series, which shows residuals after the full stripping process from the ^{214}Bi linked activity. Local disequilibrium in the uranium decay series, small gain shifts and excess scattering contributions (perhaps from irregular topographical features and flying conditions) may influence these low level statistical variations. The residual count rates of levels of ^{234m}Pa are shown in figure 3.16. There is no evidence for any localised excess signal in the terrestrial environments of the Dundrennan range which could be associated with activities on the range. Therefore within the spatial resolution of this survey we conclude that the use of depleted uranium has not contaminated the surrounding land.

It is interesting to note that elevated signals from ^{234m}Pa are seen in areas where natural uranium deposits occur. Thick shielding (water or soil) between depleted uranium and the spectrometer will attenuate signals and reduce detectability. Although the 16 litre NaI(Tl) spectrometer employed is able to locate point and distributed sources of activity, it's abilities are enhanced at lower altitudes and at slower survey speeds, owing to the reduction in the effects of spatial averaging. It would be possible to extend the effectiveness by conducting a more detailed mapping of small scale areas on the range, either at low altitude or using a vehicular approach.

In conclusion, there is no evidence to show that operations at Dundrennan have led to widespread contamination of the range and it's terrestrial surroundings by depleted uranium.

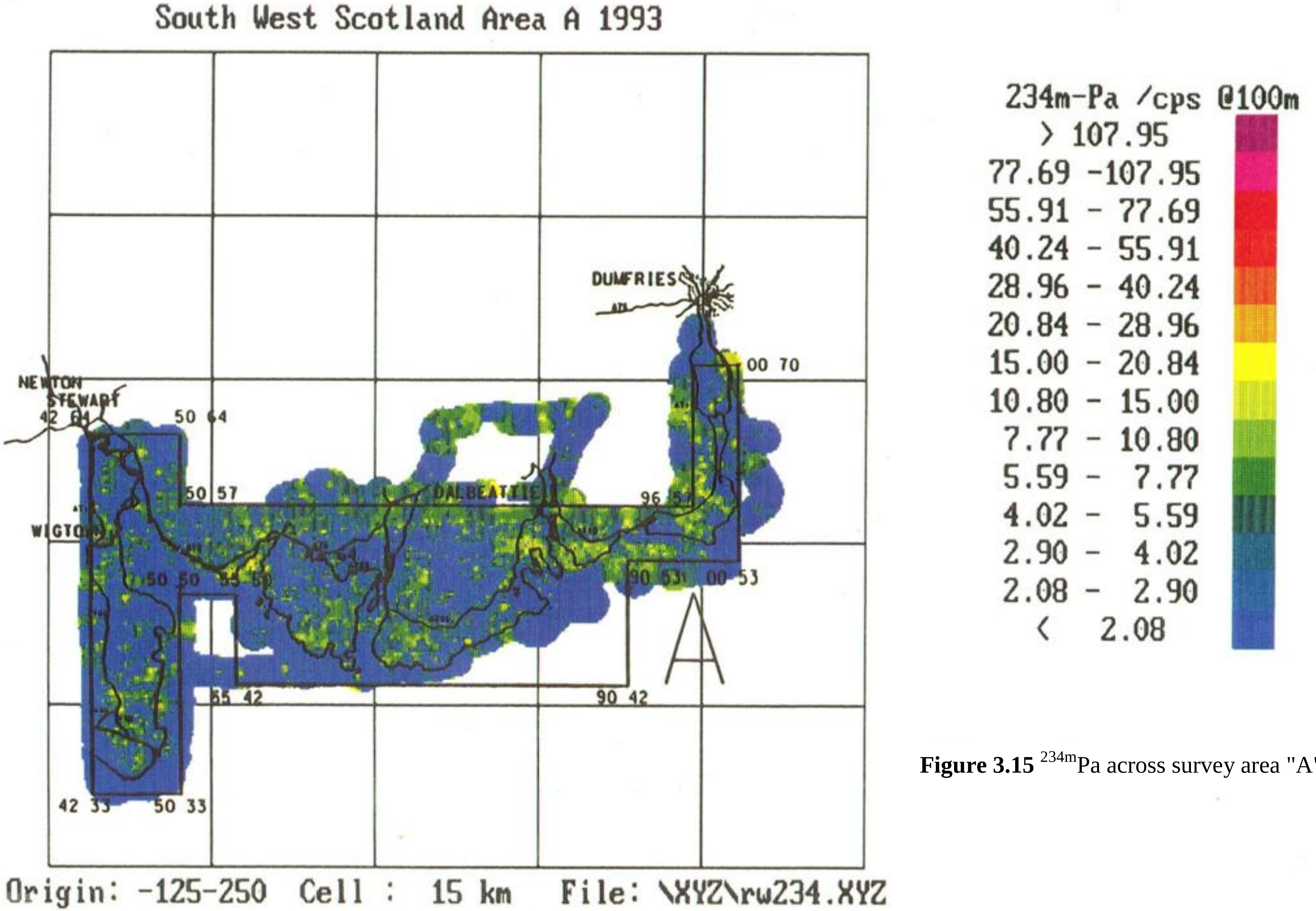


Figure 3.15 ^{234m}Pa across survey area "A"

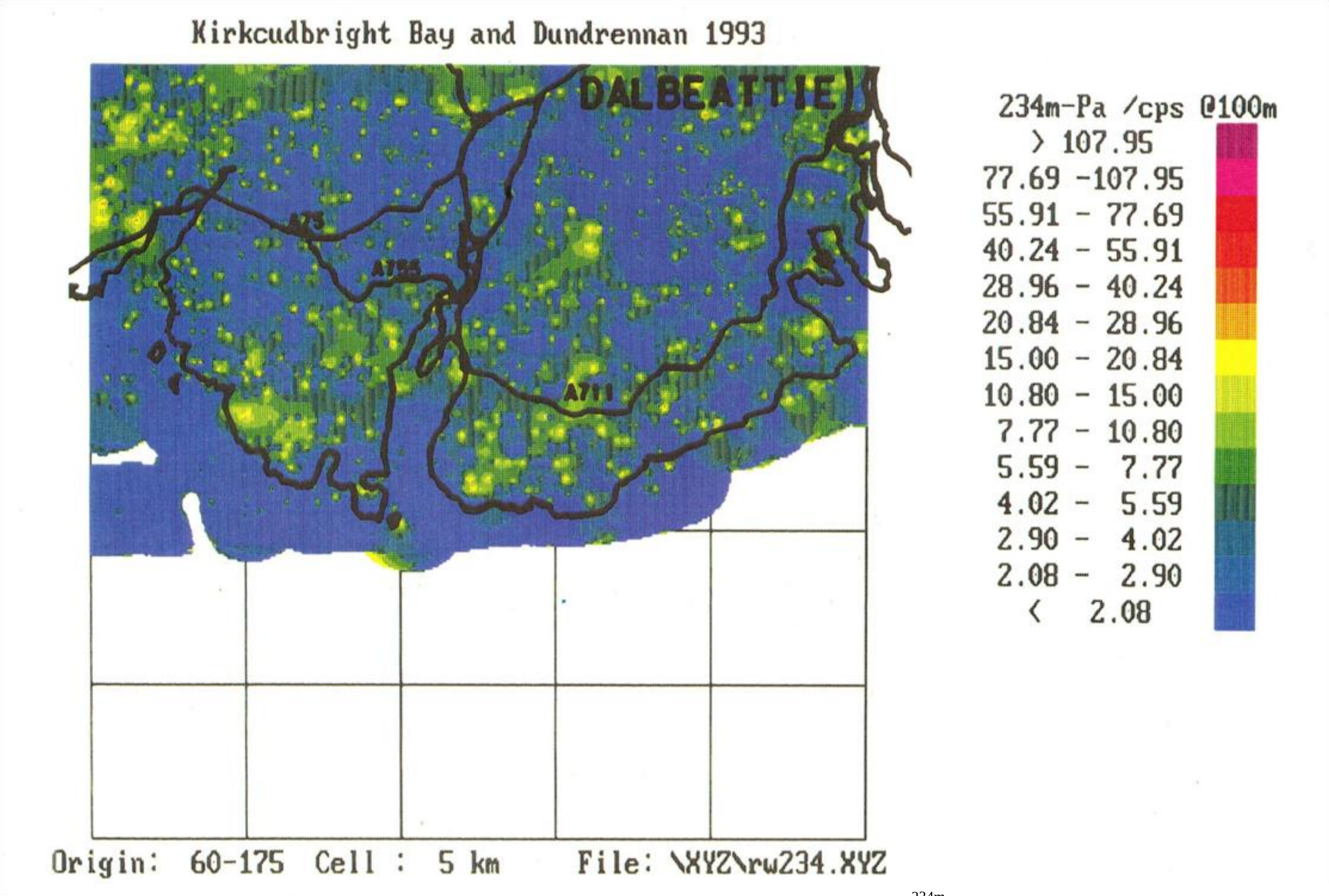


Figure 3.16 ^{234m}Pa near Kirkcudbright Bay and Dundrennan

3.8 Comparison with Related Studies

Three aerial surveys have been conducted of SW Scotland by SURRC before this project was undertaken, a further set of flights was also undertaken following this survey in March 1993[34] to compare the response of semiconductor detectors and the NaI arrays.

The first aerial survey conducted by SURRC in 1988 included flight trials[11] in the Wigtown peninsula and Mull of Galloway specifically selected to evaluate the possibility of quantifying UK Chernobyl fallout levels from aircraft. A fixed wing DAFS aircraft was used, together with a prototype detector of 7 litres of NaI based on a whole body monitoring crystal. The first confirmation that the equipment was functioning came as the aircraft descended over the mudflats to the east of Wigtown, whereupon a pronounced ^{137}Cs signal was detected. In the course of two hours several hundred observations were obtained with 1 mile line spacing, which confirmed that the higher levels of Chernobyl fallout on the Wigtown peninsula could be distinguished from the lower levels of weapons testing fallout on the Mull of Galloway. The data were calibrated approximately relative to ground based observations by Baxter et al[24], and when mapped added to the detail then available about the Chernobyl fallout distribution. The present results are broadly consistent with these early findings, but add considerable further detail as a result of the better developed detection, navigation, and quantification procedures available.

The present survey zone lies between the aerial surveys of Ayrshire [14], conducted in 1990, and Chapelcross [17] in 1992. The local authority commissioned Ayrshire survey, undertaken at 1 km line spacing, utilised the same 16 litre NaI detector, and was calibrated in a consistent manner with the overall maps. The results, which showed the distribution of Chernobyl fallout, of natural sources, and of a localised shielded source at Hunterston, are highly consistent with these findings. This is particularly true in area B where there is a slight overlap. The elevated natural radioactivity of the Loch Doon Granidiorite occurs in the same form in both sets of maps; the peak Chernobyl features in the same area are also compatible. The line spacing achieved in areas B and C matches that of the Ayrshire survey. The Chapelcross survey of 1992 was also conducted with the same detector, and a compatible terrestrial calibration. GPS navigation was used for the first time, and the line spacing of 500m complements that of the coastal zone. There is a small area of overlap adjoining the river Nith and the Criffel pluton. Again the 1992 data are highly compatible in these areas, both for natural sources and for the signals on sedimentary and tide-washed environments.

The three recent surveys, taken together, provide a complete baseline map of the coastal parts of SW Scotland from the Firth of Clyde to Gretna Green. This represents a unique environmental data base covering some 7500 km^2 of SW Scotland with more than 25,000 γ-ray spectra.

The short SURRC funded study conducted in March 1993 comprised measurement of the inland area to the east and north of this survey zone at 5 km line spacing with both semiconductor and NaI detectors, plus comparative measurements of the salt marshes at Kirkconnel and Wigtown, inland measurements of peak Chernobyl locations, and comparative measurements in West Cumbria where the upland Chernobyl activity is overprinted on earlier ^{137}Cs from Windscale. Further analysis of this data set is in progress.

These aerial surveys provide a unique reference set from which environmental changes can be measured. Furthermore they provide information on the distribution of environmental radioactivity which would be valuable in assisting with selection of sampling areas for ground based studies. The survey area has also been subject to a number of ground based studies[19-29,41-43] in the past, for a range of environmental or routine monitoring purposes. Of necessity such work relies on a limited number of samples drawn from relatively few locations. It is clear from this study that whether the focus of interest is natural radioactivity, the activity deposited from Chernobyl, or activity derived from the marine sedimentary system, there are benefits in utilising the radiometric data to produce an effective sampling scheme. A detailed analysis of the relationships between previous ground based studies and the survey results is beyond the scope of this project. However it is noted that the present results extend ground based work considerably, while maintaining general compatibility with ground based estimates of activity.

4. DISCUSSION AND CONCLUSIONS

The aims of this study, as stated in section 1, were to define the existing gamma-ray background within the survey area, to identify local features worthy of further investigation, and to demonstrate the potential of aerial radiometric methods for rapid emergency response surveying of remote areas.

4.1 The Survey and Existing Gamma-ray Background

The aerial survey itself was conducted successfully between 1st and 16th February 1993. Over 17,000 gamma ray spectra were recorded from an area of some 3650 km^2, comprising the major part of Dumfries and Galloway, and used to map the distribution of ^{137}Cs, ^{40}K, ^{214}Bi, ^{208}Tl and gamma ray dose rate. The flight time of 41.6 hours corresponded to some 4370 line kilometres of survey, covering a range of coastal, estuarine, upland pasture and forest environments. Although access to some parts of the zone was limited at various times during the survey period, on this occasion by poor visibility due to mist, and by the restricted daylight hours of a winter survey, it was nonetheless possible to complete the specified tasks within the planned time. The data were recorded, reduced and analysed during the fieldwork period, and converted to absolute activity estimates using a working calibration derived from previous surveys. It was thus possible to produce a set of preliminary radiometric maps at the end of the survey period based on the large number of gamma-ray spectra recorded.

These maps show the general distribution of ^{137}Cs, ^{40}K, ^{214}Bi, ^{208}Tl and estimated ground level dose rate in considerable detail, revealing the locations and deposition patterns of peak Chernobyl fallout, of tide washed pastures which have accumulated radioactivity as a result of past marine discharges from Sellafield, of the main distributions of natural radioactivity, in particular associated with acidic intrusions, and of the areas where increased uranium series activity may reflect potential radon enhancements. The relative importance of each of these sources to the overall gamma dose estimates can also be seen clearly, putting the balance between natural and other sources into clear context. The maps clearly show the considerable extent of spatial variations of environmental radioactivity, and have great potential to guide further ground based studies designed to investigate detailed features. The complementary nature of ground based and aerial measurements is an important feature of the potential environmental and emergency response use of this method. Therefore before considering the detailed conclusions of the radiometric maps, and their contribution towards directing site specific environmental investigations, the relationships between ground based and aerial observations will be discussed.

Ground based-sampling and in-situ measurements were undertaken, both during the fieldwork period to define activity levels on calibration sites at Caerlaverock, Longbridgemuir, and Wigtown Merse. Additional soil samples were collected from a further set of 11 inland sites in August to facilitate comparison between aerial survey estimates of Chernobyl derived fallout and those derived from ground level and laboratory based analyses. The resulting set of 54 soil cores was subdivided into 168 separate samples from high resolution gamma spectrometry.

High resolution analyses of the 168 soil samples, together with standard reference materials and background samples was conducted, full time, between April and November 1993, and enabled a comprehensive comparison of radiometric and laboratory based activity estimates for ^{137}Cs. The inland sites, and the Longbridgemuir calibration site, which is predominantly affected by Chernobyl fallout, demonstrate concordance between aerial, ground based in-situ, and core based laboratory analyses. The agreement between methods, which is within the absolute limitations of all the techniques, is impressive, and suggests that a single calibration factor could, in principle, be applied for emergency response purposes to large scale surveys of variable landscape. The concordance is consistent with the findings of previous SURRC surveys, as is the relative speed and productivity of the different approaches; aerial survey being more than 2 orders of magnitude more rapid, and providing up to 10^7 times greater sampling density (as a percentage of area examined) than in-situ or laboratory based analyses. The latter are however, as originally pointed out in the introductory sections, the appropriate means of investigating chemical speciation, vertical and physical distribution of radioactivity, and of performing definitive assessments of small scale sources.

On the two salt marsh calibration sites, at Caerlaverock and Wigtown merse, the radiation environment is dominated by the ^{137}Cs signals from past marine discharges at Sellafield. The core results confirm that the fission product inventory is associated with additional actinides, as expected, and also that relatively small quantities of the activation product ^{134}Cs are also present in the uppermost layers on these sites. The possibility that this last nuclide is partly derived from freshwater Chernobyl run-off accumulating on these sites deserves further attention, although it should perhaps be noted that ^{134}Cs was also a part of the Sellafield discharges. ^{134}Cs has been detected on Warton Bank in the Ribble [18], which is a salt marsh where Chernobyl run-off is not expected to have made a major contribution.

The main finding from the Wigtown site is a confirmation that the pronounced sub-surface maxima of activity distributions is present as previously observed at Caerlaverock and Kirkconnel, during and following the SURRC baseline survey of Chapelcross [17] (February 1992), and at Warton Bank in September 1992. This has implications for the calibration of aerial survey data from the salt marsh context, in terms of the environmental and radiological assessment and also the manner in which future ground based sampling should be conducted within such sites. The implication for aerial survey calibration is clear. Buried activity results in attenuation of the primary gamma-rays used to quantify activity per unit area, relative to the near-surface distributions observed in the majority of terrestrial environments. This was observed at Chapelcross, and in the previous survey of the Ribble. In the latter case the calibration used was selected to compensate for source burial, and estimates of ^{137}Cs derived from the aerial survey were subsequently found to be compatible with those derived from independent BNF plc analyses [18]. The extent of source burial at Wigtown merse is similar to that observed at Caerlaverock and Kirkconnel, and has been used to establish a separate relationship between activity at ground level and radiometric signals for the merse environment. This has been used to produce a data set for the coastal merse areas from which a set of detailed maps representative of 1993 levels of Sellafield derived activity, and the limits of the contaminated areas can be estimated. As far as dose rate measurements are concerned the buried activity profile influence both angular and energy distribution of the emerging photon fluence. Both aerial survey and routine dose rates instruments are affected by the angular and energy distribution of the radiation field. Therefore investigations of the influence of source burial on quantitative dosimetry for these contexts would be appropriate. As noted in the SURRC study of Chapelcross and the inner Solway, these considerations together with the geometrical signal dilution from small scale sources may lead to an underestimation of dose rates by aerial survey. It would therefore be prudent to consider further ground based investigations of the sites identified from this survey. As far as ground sampling is concerned, the vertical distribution of activity implies that surface samples, or cores to only 15cm deep, which have comprised the majority of published ground based studies of these contexts will underestimate the activity levels. Core sampling to a minimum depth of 30cm is recommended for any future work on these sites.

4.2 Detailed Findings and Future Work

The radiometric maps for ^{137}Cs confirm the importance of salt marsh (merse) sites as locations where low level discharges of radioactivity into the marine environment, from Sellafield, have accumulated. Seventeen distinct locations where this has occurred were identified by this survey, adding to the list of previously known sites. As shown in section 3, the coastal environment has received considerable attention at ground level in the past, particularly focused on intertidal sediments, and most recently on small scale sources close to the intertidal limits of the main rivers in the areas where localised activity levels exceed those observed from the air by factors of 3 or more. The aerial survey by contrast has identified some more extensive areas where overall quantities of activity are deposited, mainly as a result of the accumulation of sedimentary material in the salt marsh context. The majority of these sites are designated as of special scientific interest, and incidentally represent the main overwintering grounds for some arctic geese. The external gamma-ray dose of these contexts is dominated by Sellafield derived activity. They are clearly sites which act as environmental sinks for marine pollution and for this reason merit further long term attention. As far as environmental radiation is concerned, the main priorities are to review critical group exposures, taking occupancy and the buried source characteristics into account, and to conduct time series measurements which can indicate whether radiation levels are rising or falling on these sensitive sites. Broader ecological studies may be of scientific value.

The inland distribution of ^{137}Cs reveals further detail of the Chernobyl deposition in this part of Scotland. Importantly it confirms the highly variable nature of such deposition, which can only be mapped at high resolution using remote sensing techniques of this type, and suggests that the prevailing trajectories for the radioactive plumes, may have been oriented NS to a greater degree than previously supposed. This itself may explain the presence of Chernobyl activity in the Central Highlands of Scotland. When the previously conducted aerial surveys of Ayrshire and the environment of Chapelcross are juxtaposed it can be seen that both eastern and western limits of the main Chernobyl deposition zone have been defined in SW Scotland. Between these two margins there exists an extremely valuable range of different soil types, landscapes and environments where the main source of ^{137}Cs is derived from Chernobyl, and can therefore be associated temporally with deposition in 1986. The complexity of the deposition pattern can be seen clearly from the radiometric maps, incorporating both upland, and lowland contexts. There is considerable further scope for studies of the environmental distribution of activity, and the pathways whereby ^{137}Cs is recycled through agronomy and wildlife in these areas. Whereas the majority of such work in the UK has been focused on the problem with sheep in the livestock movement restriction zones of West Cumbria, and to a lesser extent North Wales, these studies have been limited by ambiguities concerning the relative proportions of Chernobyl and aged fallout in West

Cumbria, and by the limited extent of deposition from Chernobyl in the Snowdonia region. Neither such limitation exists in SW Scotland, and of the areas of the UK mapped so far by aerial radiometrics, a case could be made for focusing a greater proportion of UK countermeasures research into these contexts than hitherto.

The natural maps show the levels and variability of K, U and Th, reflecting both subsoil geology and overburden. Granite intrusions are clearly visible, as are ^{214}Bi signals associated with potential radon sources of radiation exposures to the human population, the distribution of uranium series activity, particularly ^{226}Ra and the relationship between the natural distribution of such sources and levels of radon in the soil and indoors assumes considerable importance. There is scope for further detailed work to examine the relationships between the ^{214}Bi distribution recorded in this survey, the permeability of the local rocks, and radon levels in soil and in houses in the area. There is considerable variation in uranium series activity throughout the survey region, and would be of long term value to examine the influence, if any, which this has on radiation exposure to the population.

The overall gamma-ray dose rate maps show that natural radioactivity is responsible for the majority of radiation exposure, although external radiation from marine derived anthropogenic activity on merse sites controls the local radiation dosimetry. The environment of Dumfries and Galloway is complex, since many different sources of activity are represented within a geographically compact area. However the results of this survey have defined present day levels in a comprehensive manner which will allow any future changes to be clearly defined.

4.3 The Emergency Response Potential of Aerial Surveys in Scotland

Since the Chernobyl nuclear accident in 1986, there has been an increasing awareness that radioactive contamination can extend across national and international boundaries, and can lead to extensive fallout covering large areas.

The limitations of ground based methods for national mapping are quite apparent; following Chernobyl the UK core based analysis programme, covering some 200-300 sites took about 3 years; for this reason the initial agricultural countermeasures (definition of livestock restriction zones) were based on deposition estimates derived from a combination of early monitoring results and meteorological data. Of necessity the areas defined initially bore a variable relationship to the deposition patterns, in some cases leading to considerable over-restriction; in other cases to areas being overlooked. The meteorological approach depends on a combination of information about air flows, rainfall, and a knowledge of the locations of radioactive plumes. In the absence of the latter it may be possible to make inferences by folding the results of deposition measurements into models, to back-calculate where the radioactive clouds have been. However this procedure must be used with extreme caution, since it introduces a form of positive feedback into the predictive process, whereby early monitoring results are reinforced in deposition patterns, leading to misplaced concentration of ground based efforts. Again, the post-Chernobyl experience provides an example of the pitfalls of such a combination of circumstances; enhanced rainfall in the Central Highlands was recorded by rain gauges, but the consequent elevated deposition from Chernobyl was not recognised in UK national fallout maps [27,28] until the publication in 1990 [29] of the results of direct measurements in this area, resulting from environmental sampling, and the results of an exploratory aerial survey conducted at the end of 1988 by SURRC.

Radioactive pollution on a large scale is an understandable cause of considerable public anxiety, and the experience of Chernobyl demonstrates the problems which might arise if such circumstances were to be repeated. There has been substantial progress since 1986, and it is hoped that international agreements on the notification of accidents, that the IAEA INES system, and that fixed monitoring networks such as RIMNET, would provide an early indication of any future event of similar scale. Furthermore it might be hoped that resources would be directed towards the areas of the country which are most vulnerable in any future radioactive accident. For Scotland, the impact of radioactive contamination from the Chernobyl nuclear accident was relatively greater than most other parts of the United Kingdom. This was due to the weather conditions prevailing at the time that the Chernobyl cloud passed over the UK leading to enhanced wet deposition in upland agricultural areas. These are precisely those susceptible environments which are difficult to monitor effectively by ground based methods, and which have the necessary soil characteristics to transfer nuclides to grazing animals.

Whether this scenario, or any other, recurs in the future it is important that national response plans contain mobile monitoring capability, and that this capability is effective in remote, vulnerable environments such as those affected by Chernobyl. It is clearly desirable that central and local government, should have reliable information on the distribution of radioactive fallout following any nuclear accident with the minimum delay, and that countermeasures and public statements should be informed by such data. Aerial survey is probably the only technology that is capable of assessing the level of contamination in populated and remote areas, rapidly and economically, at regional or national scale.

Aerial radiometrics has been adopted in the United States for more than two decades as an emergency tool. The model adopted has been to equip and maintain several aircraft for continuous availability, with deployment in both east coast and western locations. At present four helicopters equipped with 16 litre NaI detectors and 256 channel spectrometers are kept in a condition of preparedness for nuclear accidents. This of course is an expensive option which requires the combination of technical staff to service and maintain the spectrometers, and aircrew to ensure aircraft availability. The fixed installations are potentially vulnerable to contamination if flown through radioactive plumes.

An alternative approach, which has been developed by SURRC as a means to providing low cost emergency standby capabilities for nuclear sites in the UK, is to maintain duplicated gamma-ray spectrometers in the laboratory, ready for rapid deployment in chartered aircraft in the event of an emergency. This has more than economic advantages, in that the equipment can be kept in a state of readiness by specialists who are usually engaged in other, related, research tasks. The current generation of spectrometers, including that used for this survey, are compact, require little interfacing to appropriate aircraft, and can be installed within 30-60 minutes of an aircraft arriving on site. They can also be used from vehicles if necessary to provide data at ground level if conditions precluded flying, and could be readily moved from one aircraft to another in the event of contamination. Since the introduction of satellite positioning and navigation systems it is possible to record latitude and longitude automatically without the use of external beacons. This has an important practical effect on the operator workload during survey. Each aerial survey helicopter unit can now be flown successfully with a minimum of one pilot and operator, although in poor weather or restricted flying zones, it may be advisable to supplement this with a co-pilot or an experienced survey member.

For effective communication of results and rapid interpretation, the colour mapping of survey areas can proceed immediately after the in-flight recorded summarization data has been down-loaded to floppy discs and transferred to standard PC based computers. After suitable data processing, the data is in a form that is compatible with other computer based mapping systems. The rapid display of survey results, after the helicopter has landed, enables decisions to be made in constantly changing circumstances. Overall therefore both the technology and methodology of aerial surveys have advanced since 1986 to an extent which provides obvious practical opportunities for incorporation into national emergency response planning.

This survey has demonstrated the productivity of the method, the compatibility of the results with those derived from other, slower, methods, and the spatial variability of radioactivity deposited in the environment following the Chernobyl accident, which could not have been adequately described by a limited number of ground based samples. The survey of some 4370 line km in 41.6 hours represents a practical rate of survey of over 100 line kilometres per hour, and a spectral acquisition rate of some 300 spectra per hour. It is instructive to consider the scale of the task of preparing national maps, either for baseline purposes, or for emergency response using these figures for guidance.

Table 4.1 shows the approximate land area of Scotland, broken down into "mainland" (including the Isles of Mull and Skye), Shetland, Orkney, Harris & Lewis Isles.

Table 4.1 Approximate land areas of Scotland

	Approx. Land Area / km^2
Mainland, inc. Isles of Arran, Mull and Skye	77870
Shetland Isles	2605
Orkney Isles	2924
Harris and Lewis Isles	2618
Total	86017

It is notable that high resolution surveys of Shetland, Orkney, or the Western Isles would individually represent surveys of smaller scale than this present project.

To March 1993, the total area of Scotland surveyed by SURRC amounts to approximately 8210 km^2. This has included studies commissioned by The Scottish Office (1993), BNF plc [17] and the District Councils of Cunninghame, Kilmarnock & Loudon, and Kyle & Carrick [14]. As a percentage of land area, this represents 9.5% and 10.5% of total and mainland respectively.

On the basis of the Scottish Office Survey 1993, it is possible to estimate line kilometres and flying time to enable the remaining mainland and total Scotland to be surveyed. With the assumptions that, with good planning, appropriate support from ground base locations, helicopter availability and favourable weather conditions, table 4.2 shows approximate estimates of line kilometres and flying hours required to conduct radiometric surveys at varying line spacings from 1 to 20 km. It can be seen that a complete survey of mainland Scotland and the Inner Hebrides could be conducted within roughly one week using a single aircraft at 20 km line spacing, and that 5 km and 2 km line spacing surveys would require roughly 150 and 390 flying hours respectively.

Table 4.2 Estimated line kilometres for the *remaining* areas of Scotland

	Estimated Line Kilometres		
Line Spacing / km	**Mainland Scotland**	**Total**	**Estimated Flying Time / hours**
1	69660	77807	780
2	34830	38904	390
5	13932	15561	150
10	6966	7781	80
20	3483	3890	40

The technology clearly exists to provide effective, and economical emergency response. The scale of surveys required for detailed national mapping is such that initial national scale mapping at, say 5 or 10 km line spacing could be achieved rapidly, and followed by a series of higher resolution surveys to define the detailed deposition patterns over the following weeks or months. The results could certainly direct ground based analyses, and in some cases could inform counter measure decisions directly.

Maintenance of long term capability in this field would be most effectively ensured by conducting a regular series of surveys, aimed jointly at defining the existing baseline, and at exercising and developing the survey expertise of both detector operators and flight crew. Adoption of an intermediate target, for example of conducting annual surveys equivalent to a national 5 or 10 km line spacing survey, would achieve these aims, and also result in the production, over a 5-10 year timescale of high resolution radioactivity maps for the entire country, which serve as the basis for environmental and epidemiological research, and could provide a detailed record of environmental changes which re-distribute the activity due to Chernobyl. Such a programme would be a cost effective solution to the maintenance of an airborne radiometric emergency response capability, and would be of independent value regardless of whether or not there is another nuclear accident in the foreseeable future.

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APPENDIX A.

SUMMARY OF DETECTOR CALIBRATION : SW SCOTLAND SURVEY FEBRUARY 1993

1) Detector

16 l NaI detector - box of 4 10x10x40cm NaI crystals
Resolution <=12% at 662 keV
DPS MkII power supply
Locland Computer
SURRC 19" RACK INSTALLATION
Recording with MCA29A(5S), MCA29B(10S) software
Radalt 10 mV/ft output
Data processing software: AERO201/AERO202

2) Windows

Window	**Nuclide**	**Channels**	**Background (cps)**
1	^{137}Cs	95-128	85.1
2	^{134}Cs	125-150	34.6
3	^{40}K	220-270	30.1
4	^{214}Bi	270-318	18.5
5	^{208}Tl	390-480	13.7
6	>450 keV	75-500	306

3) Stripping Factors (air equivalent of 80m)

Window	1	2	3	4	5
1	1	0.01	0	0	0
2	1.77	1	0.03	0	0
3	0.69	0.383	1	0.02	0
4	3.50	1.41	0.95	1	0.17
5	2.89	1.54	0.663	0.498	1

4) Calibration Constants
a: exponential altitude coefficient
b: slope of calibration line
c: calibration intercept

Window	Nuclide	a	b	c
1	^{137}Cs	0.00962	0.198	0
2	^{134}Cs	0.0075	0.131	0
3	^{40}K	0.006	2.79	0
4	^{214}Bi	0.0066	0.606	-0.67
5	^{208}Tl	0.004	0.245	-0.2
6	>450 keV	0.0062	0.0007	0.0

5) Mapping Coordinates

Latitude and Longitude of Grid Origins:

(NX 500 500): 54.823°N, 4.336°W, φ=1.7°
(NX 000 000): 54.4625°N, 5.097°W, φ=1.5°

APPENDIX B.

Table B.1 Integrated Inventories from the Expanding Hexagon at Wigtown Bay Salt Marsh

Activity kBq m^{-2}	**Hexagonal Spacing /m**					
	Centre	**2**	**8**	**32**	**128**	**256**
^{137}Cs						
Range	-	134.9-172.2	115.6-228.8	105.7-173.6	124.2-178.7	98.6-288.4
Mean	138.04	145.79	164.92	133.09	160.24	204.96
Std. Dev.	6.39	13.79	41.62	29.36	19.64	68.27
Variance %	4.6	9.5	25.2	22.06	12.2	33.3
^{40}K						
Range	-	122.1-185.9	162.3-201.1	118.9-200.5	157.3-185.0	125.2-194.9
Mean	154.39	162.38	181.20	162.91	170.56	178.43
Std. Dev.	2.77	22.67	15.06	31.19	10.77	27.14
Variance %	1.8	13.9	8.3	19.1	6.3	15.2
^{214}Bi						
Range	-	6.2-12.9	9.4-12.2	7.7-15.0	8.7-11.6	6.7-12.6
Mean	8.56	10.09	11.04	11.32	10.20	10.94
Std. Dev.	1.37	2.26	0.99	2.71	1.21	2.17
Variance %	16.0	22.4	8.9	23.9	11.9	19.8
^{208}Tl						
Range	-	2.4-3.6	2.8-3.7	2.6-4.6	2.7-3.6	2.3-3.9
Mean	2.47	2.96	3.18	3.37	3.18	3.32
Std. Dev.	0.25	0.43	0.34	0.68	0.31	0.55
Variance %	10.1	14.5	10.7	20.2	9.7	16.6

Table B.2 Integrated inventories from the Expanding Hexagon at Wigtown Bay Salt Marsh

Activity Bq kg^{-1} (wet)	**Hexagonal Spacing /m**					
	Centre	**2**	**8**	**32**	**128**	**256**
^{40}K						
Range	-	265.2-397.7	349.5-425.4	287.1-407.9	359.0-401.3	324.5-407.1
Mean	358.6	354.6	383.5	364.2	377.6	381.2
Std. Dev.	12.7	45.6	29.2	41.1	17.5	34.3
Variance %	3.5	12.8	7.6	11.3	4.6	9.0
^{214}Bi						
Range	-	13.5-27.7	20.8-24.7	20.8-25.9	19.6-26.6	17.4-26.8
Mean	20.7	21.3	23.3	23.8	22.5	23.3
Std. Dev.	6.4	4.2	1.2	1.7	2.4	2.9
Variance %	30.9	19.7	5.2	7.1	10.7	12.4
^{208}Tl						
Range	-	5.37-7.64	6.20-7.44	5.72-7.24	6.22-7.59	5.89-8.25
Mean	5.7	6.45	6.87	6.73	6.85	7.10
Std. Dev.	1.2	0.71	0.42	0.47	0.50	0.72
Variance %	21.1	11.0	6.1	7.0	7.3	10.1

Table B.3 Wigtown Bay calibration site: ^{40}K Bq m^{-2}

^{40}K: 16 litre detector at 100m altitude					
Radius /m	% weighting	% Cumulative weighting	Activity /kBq m^{-2}	Std. Dev.	Std. Er.
2	1	1	162.383	22.674	9.257
8	2	3	181.820	15.061	6.149
32	32	35	162.910	31.190	12.733
128	45	80	170.557	10.768	4.396
256	20	100	178.426	27.141	11.080
		Mean	169.827	20.783	8.484

Table B.4 Wigtown Bay calibration site: ^{214}Bi Bq m^{-2}

^{214}Bi: 16 litre detector at 100m altitude					
Radius /m	% weighting	% Cumulative weighting	Activity /kBq m^{-2}	Std. Dev.	Std. Er.
2	1	1	10.089	2.262	0.923
8	2	3	11.038	0.993	0.405
32	32	35	11.320	2.706	1.105
128	45	80	10.204	1.213	0.495
256	20	100	10.942	2.171	0.886
		Mean	10.724	1.888	7.708

Table B.5 Wigtown Bay calibration site: ^{208}Tl Bq m^{-2}

^{208}Tl: 16 litre detector at 100m altitude					
Radius /m	% weighting	% Cumulative weighting	Activity /kBq m^{-2}	Std. Dev.	Std. Er.
2	1	1	2.964	0.428	0.175
8	2	3	3.173	0.337	0.138
32	32	35	3.372	0.677	0.276
128	45	80	3.177	0.314	0.128
256	20	100	3.324	0.550	0.225
		Mean	3.266	0.480	0.196

Table B.6 Wigtown Bay calibration site: ^{40}K Bq kg^{-1}

^{40}K: 16 litre detector at 100m altitude					
Radius /m	% weighting	% Cumulative weighting	Activity /Bq kg^{-1}	Std. Dev.	Std. Er.
2	1	1	353.6	45.6	18.6
8	2	3	383.5	29.2	11.9
32	32	35	364.2	41.1	16.8
128	45	80	377.6	17.5	7.1
256	20	100	381.2	34.3	14.0
		Mean	373.91	28.93	11.8

Table B.7 Wigtown Bay calibration site: ^{214}Bi Bq kg^{-1}

^{214}Bi: 16 litre detector at 100m altitude					
Radius /m	% weighting	% Cumulative weighting	Activity /Bq kg^{-1}	Std. Dev.	Std. Er.
2	1	1	21.3	4.2	1.71
8	2	3	23.3	1.21	0.49
32	32	35	23.8	1.7	0.69
128	45	80	22.5	2/4	1.10
256	20	100	23.3	2.9	1.20
		Mean	23.1	2.3	0.90

Table B.8 Wigtown Bay calibration site: ^{208}Tl Bq kg^{-1}

^{208}Tl: 16 litre detector at 100m altitude					
Radius /m	% weighting	% Cumulative weighting	Activity /Bq kg^{-1}	Std. Dev.	Std. Er.
2	1	1	6.45	0.71	0.29
8	2	3	6.87	0.42	0.17
32	32	35	6.73	0.47	0.19
128	45	80	6.85	0.50	0.20
256	20	100	7.11	0.72	0.29
		Mean	6.86	0.53	0.22

APPENDIX C. GROUND SAMPLES

WIGTOWN BAY COMPILATION Bq/kg for anthropogenics and Bq/wet kg for naturals											
	Filename "GSP"	**^{241}Am 59.5 / keV**	**^{208}Tl 583**	**^{214}Bi 609**	**^{137}Cs 662**	**^{134}Cs 796**	**^{228}Ac 911**	**^{228}Ac 969**	**^{40}K 1462**	**^{214}Bi 1764**	**^{208}Tl 2615**
WIG 01 0-2	13006	325.30	6.57	34.57	574.46	-0.17	14.43	18.53	363.08	34.89	4.12
	±1σ	14.28	2.10	6.27	8.01	-3.21	8.77	18.24	35.28	18.81	3.72
WIG 01 2-5	10057	382.28	4.62	16.07	1190.19	22.79	13.31	15.80	319.87	18.01	4.70
	±1σ	60.65	0.62	2.32	82.98	1.78	2.06	5.18	13.85	5.82	1.05
WIG 01 5-10	20021	536.50	6.18	16.30	1911.75	7.43	15.91	19.36	380.23	22.37	4.35
	±1σ	88.39	0.78	2.80	136.00	1.21	1.87	3.99	13.17	5.93	0.87
WIG 01 10-15	20022	134.35	6.80	22.69	537.03	-0.29	20.65	23.86	378.75	17.72	5.79
	±1σ	22.17	0.78	3.28	38.33	-0.77	2.05	4.48	13.00	5.51	0.88
WIG 01 15-20	20023	2.31	5.10	19.07	67.09	2.53	15.11	20.05	312.46	20.70	4.94
	±1σ	0.72	0.58	2.67	4.85	0.81	1.56	3.66	10.54	4.92	0.71
WIG 01 20-30	20024	0.34	6.86	23.91	11.32	0.77	19.80	25.95	369.41	17.32	5.59
	±1σ	0.60	0.77	3.36	1.12	0.79	2.02	4.73	12.90	5.39	0.90
WEIGHTED MEAN			6.24	21.68			17.68	22.29	358.62	19.78	5.16

ERROR			0.75	3.11			2.12	4.79	12.73	5.59	0.94
WIG 11 0-15	10060	375.46	6.99	19.67	1149.66	6.07	12.97	8.85	286.51	4.56	4.77
	±1σ	59.59	0.63	2.28	80.57	0.83	1.84	4.27	13.06	4.85	1.02
WIG 11 15-30	10065	1.22	6.26	18.56	23.70	0.82	10.60	10.56	246.13	11.06	3.58
	±1σ	0.58	0.59	2.27	1.80	0.69	2.18	5.10	13.54	5.61	1.05
WEIGHTED MEAN			6.61	19.08			11.72	9.76	265.19	7.99	4.14
ERROR			0.86	3.22			2.89	6.73	18.88	7.49	1.47
WIG 12 0-15	20048	327.16	7.64	20.40	1134.22	7.07	21.92	22.03	435.03	37.40	6.86
	±1σ	53.88	0.94	3.38	80.34	1.21	2.35	4.66	15.33	8.06	1.09
WIG 12 15-30	10064	1.09	5.94	20.43	33.10	0.06	15.16	11.39	246.35	13.84	5.18
	±1σ	0.61	0.50	1.96	2.43	0.75	1.82	4.07	11.84	4.84	1.01
WEIGHTED MEAN			7.05	21.31			19.20	17.19	351.21	26.19	6.25
ERROR			1.08	3.99			3.07	6.43	20.01	9.61	1.54
WIG 13 0-5	10061	385.89	5.04	18.92	896.64	15.01	12.78	14.74	246.67	22.71	3.68
	±1σ	61.20	0.54	2.03	62.37	1.31	1.68	3.90	11.33	5.35	0.86
WIG 13 5-15	10062	390.39	6.14	23.04	911.48	15.30	15.56	17.95	300.35	27.65	4.48

	±1σ	61.90	0.66	2.47	63.27	1.34	2.04	4.75	13.80	6.52	1.05
WIG 13 15-30	10063	-0.68	6.84	22.29	14.78	2.12	15.81	11.13	289.93	13.88	5.78
	±1σ	-0.57	0.61	2.33	1.21	0.68	2.14	5.05	14.42	5.73	1.18
WEIGHTED MEAN			6.36	22.05			15.30	13.80	287.09	19.49	5.07
ERROR			0.81	3.05			2.73	6.40	18.36	7.68	1.48
WIG 14 0-2	23004	439.11	7.47	14.47	489.14	4.34	16.90	39.47	338.02	9.55	18.23
	±1σ	25.06	1.29	3.72	6.30	3.02	4.64	11.56	28.32	12.93	3.04
WIG 14 2-5	20032	365.54	6.75	13.00	1207.79	23.23	17.65	18.02	351.05	24.64	5.66
	±1σ	60.12	0.81	2.54	84.91	3.11	1.98	3.93	12.71	6.05	0.91
WIG 14 5-10	20033	568.07	6.74	23.34	1888.58	4.93	19.58	17.91	377.18	20.71	6.90
	±1σ	93.59	0.84	3.52	134.32	0.99	2.06	3.90	13.31	6.06	0.98
WIG 14 10-15	10052	114.98	7.18	20.19	577.21	1.57	16.78	31.89	381.79	16.75	8.04
	±1σ	18.28	0.66	2.42	40.57	0.71	2.34	5.93	16.01	6.36	1.40
WIG 14 15-20	10053	2.26	6.85	22.53	74.71	1.28	24.26	28.18	417.31	15.80	7.05
	±1σ	0.70	0.63	2.43	5.34	0.69	2.53	6.24	17.15	6.39	1.33
WIG 14 20-30	10054	0.31	6.84	23.48	11.67	-0.33	20.63	35.94	423.99	35.70	8.79
	±1σ	0.58	0.65	2.49	1.09	-0.71	2.57	6.40	17.61	8.12	1.49

WEIGHTED MEAN			6.90	21.34			20.04	29.59	397.52	24.47	8.28
ERROR			0.68	2.57			2.45	5.97	16.56	7.35	1.39
WIG 15 0-2	13004	221.28	5.99	24.13	479.79	1.85	33.00	44.84	422.73	29.13	8.10
	±1σ	9.72	1.58	4.87	6.00	1.94	6.09	12.70	37.96	15.99	3.13
WIG 15 2-5	10037	296.16	6.48	25.86	516.39	3.19	20.10	24.41	402.10	21.56	6.13
	±1σ	47.03	0.68	2.65	36.39	0.75	2.46	6.22	16.88	7.09	1.21
WIG 15 5-10	10038	269.68	5.34	19.25	994.85	13.45	16.63	30.07	369.18	26.63	7.53
	±1σ	42.84	0.71	2.68	70.17	1.17	2.39	6.07	15.84	7.15	1.36
WIG 15 10-15	10039	393.82	8.01	23.72	1698.56	3.32	17.10	34.51	414.38	27.89	7.95
	±1σ	62.49	0.84	3.09	118.79	0.75	2.63	6.90	17.59	7.49	1.46
WIG 15 15-20	10040	610.92	6.05	21.47	1585.39	1.77	18.22	23.74	403.67	21.29	6.52
	±1σ	97.09	0.75	2.82	112.74	0.67	2.37	5.90	16.57	6.63	1.25
WIG 15 20-30	10041	62.55	8.87	28.87	230.40	2.55	25.00	29.99	411.41	26.12	5.55
	±1σ	9.96	0.73	2.78	16.14	0.74	2.73	6.84	17.61	7.55	1.29
WEIGHTED MEAN			7.29	24.74			21.25	29.96	403.45	25.38	6.61
ERROR			0.74	2.78			2.65	6.59	17.31	7.39	1.32

WIG 21 0-15	20038	334.02	5.52	15.64	1059.36	9.08	17.12	21.81	327.07	17.45	4.01
	±1σ	55.02	0.68	2.53	75.24	1.40	1.78	4.10	11.37	5.04	0.74
WIG 21 15-30	10073	1.92	7.26	25.69	43.01	1.56	21.18	31.57	388.73	24.89	9.99
	±1σ	0.68	0.63	2.45	3.13	0.73	2.45	6.49	16.44	7.31	1.64
WEIGHTED MEAN			6.48	21.18			19.36	27.19	361.05	21.55	7.31
ERROR			0.94	3.62			3.22	8.25	21.32	9.48	1.98
WIG 22 0-15	10066	337.20	6.03	25.31	1089.29	7.76	13.48	6.12	266.50	8.72	4.40
	±1σ	53.50	0.66	2.47	75.97	0.93	1.98	4.71	13.28	5.35	1.09
WIG 22 15-30	10067	0.58	7.55	30.91	22.21	0.93	17.80	36.89	421.13	28.36	6.56
	±1σ	0.61	0.67	2.67	1.69	0.75	2.39	6.08	17.18	7.68	1.32
WEIGHTED MEAN			6.85	28.32			15.80	22.63	349.48	19.26	5.56
ERROR			0.97	3.78			3.26	8.12	22.95	9.98	1.80
WIG 23 0-5	10056	250.96	6.59	21.54	755.87	15.00	12.44	16.64	348.07	14.53	5.68
	±1σ	39.85	0.64	2.41	53.09	1.28	2.18	5.44	14.88	6.18	1.10
WIG 23 5-15	10068	219.66	7.15	21.90	941.30	3.07	17.30	22.87	353.22	33.05	6.17
	±1σ	34.91	0.66	2.46	66.49	0.67	2.02	4.72	14.52	6.88	1.10

WIG 23 15-30	10069	4.17	7.26	25.25	53.37	1.37	21.82	30.86	377.83	29.40	7.05
	±1σ	0.90	0.61	2.35	3.82	0.72	2.24	5.25	15.56	6.89	1.24
WEIGHTED MEAN			7.12	23.65			18.99	26.22	365.71	28.21	6.57
ERROR			0.64	2.43			2.18	5.15	15.32	6.92	1.19
WIG 24 0-15	10070	463.88	5.49	21.80	1412.40	6.79	17.12	14.96	343.00	7.55	6.55
	±1σ	73.58	0.65	2.41	98.41	0.91	2.10	5.25	14.22	5.76	1.17
WIG 24 15-30	10071	44.16	7.03	28.31	176.61	1.95	22.28	25.80	393.09	32.60	9.08
	±1σ	7.05	0.64	2.45	12.32	0.77	2.47	6.27	16.21	7.73	1.52
WEIGHTED MEAN			6.36	25.48			20.04	21.09	371.31	21.71	7.98
ERROR			0.91	3.45			3.32	8.38	21.99	10.02	1.98
WIG 25 0-15	10055	340.69	7.01	21.66	1346.19	9.43	9.55	31.32	350.19	17.90	6.99
	±1σ	54.10	0.71	2.59	94.72	0.98	2.29	5.82	14.99	6.40	1.25
WIG 25 15-30	10072	3.13	7.05	24.59	42.39	0.39	24.34	27.44	375.31	29.53	6.59
	±1σ	0.75	0.63	2.49	3.10	0.67	2.50	6.34	16.10	7.82	1.37
WEIGHTED MEAN			7.04	23.29			17.76	29.17	364.14	24.36	6.77
ERROR			1.00	3.83			3.66	9.30	23.72	11.05	2.01

WIG 31 0-15	10074	321.95	6.95	22.24	994.96	7.77	20.39	20.43	359.73	20.54	6.90
	±1σ	51.12	0.63	2.32	69.92	0.90	2.10	5.27	14.51	6.17	1.18
WIG 31 15-30	10075	2.16	8.67	27.57	31.86	-0.29	27.04	30.85	431.78	39.12	7.91
	±1σ	0.70	0.68	2.58	2.38	-0.76	2.67	6.60	17.84	8.74	1.44
WEIGHTED MEAN			7.86	25.05			23.90	25.93	397.75	30.34	7.43
ERROR			0.94	3.52			3.47	8.62	23.46	10.98	1.90
WIG 32 0-15	20075	253.63	6.04	12.45	1018.98	5.48	15.95	17.96	349.58	17.45	5.50
	±1σ	41.72	0.78	2.53	71.40	1.10	1.96	4.07	13.08	5.87	0.95
WIG 32 15-30	10080	0.63	8.29	29.42	45.84	1.17	23.51	15.41	439.39	30.78	9.23
	±1σ	0.59	0.65	2.55	3.34	0.67	2.56	6.42	17.61	8.04	1.56
WEIGHTED MEAN			7.30	21.94			20.18	16.53	399.82	24.91	7.58
ERROR			1.05	3.79			3.50	8.40	23.87	10.85	2.02
WIG 33 0-5	20076	255.87	4.52	8.59	662.19	6.51	11.75	14.64	288.08	17.32	5.15
	±1σ	42.08	0.59	1.91	46.44	1.21	1.57	3.33	10.81	5.14	0.82
WIG 33 5-15	10047	335.76	5.61	20.29	1230.89	6.98	15.75	21.03	357.74	28.89	7.28
	±1σ	53.24	0.71	2.69	85.30	0.92	2.41	6.03	15.80	7.33	1.34

WIG 33 15-30	20078	-0.18	7.51	24.77	52.60	-0.37	21.01	22.00	420.38	31.48	7.66
	±1σ	-0.64	0.87	3.63	3.83	-0.83	2.29	4.68	15.16	7.42	1.12
WEIGHTED MEAN			6.47	21.13			18.01	20.71	381.72	28.75	7.20
ERROR			0.81	3.26			2.38	5.43	15.71	7.50	1.25
WIG 34 0-15	20041	384.01	5.73	20.79	1284.01	6.75	17.12	17.81	354.31	15.32	6.09
	±1σ	63.25	0.71	3.11	91.10	1.19	1.84	3.70	12.33	5.07	0.87
WIG 34 15-30	20077	-1.46	5.87	25.79	14.68	-0.09	21.61	12.06	382.84	27.09	7.12
	±1σ	-0.61	0.71	3.64	1.28	-0.69	2.22	3.49	13.83	6.75	1.00
WEIGHTED MEAN			5.80	23.41			19.47	14.80	369.26	21.49	6.63
ERROR			1.03	4.90			2.95	5.15	18.91	8.68	1.36
WIG 35 0-15	20039	525.99	6.63	26.44	1902.54	4.98	21.95	24.62	405.64	27.71	7.66
	±1σ	86.37	0.85	3.87	132.37	1.09	2.23	4.77	14.16	6.68	1.05
WIG 35 15-30	20074	1.75	6.85	25.91	40.01	2.37	24.38	21.25	408.36	14.59	9.02
	±1σ	0.70	0.82	3.74	2.96	0.86	2.48	4.59	14.85	6.10	1.18
WEIGHTED MEAN			6.75	26.15			23.25	22.81	407.10	20.66	8.39
ERROR			1.21	5.52			3.45	6.78	21.15	9.23	1.64

WIG 41 0-15	20051	335.92	5.95	19.47	1129.81	4.19	18.18	19.50	345.81	14.14	6.83
	±1σ	55.24	0.73	2.98	79.32	1.00	1.95	3.99	12.33	5.25	0.94
WIG 41 15-30	20052	9.68	6.77	23.02	68.46	2.29	19.52	20.41	396.71	23.90	6.42
	±1σ	1.73	0.79	3.35	4.94	0.81	2.11	4.25	13.92	6.10	0.98
WEIGHTED MEAN			6.42	21.50			18.94	20.02	374.83	19.71	6.60
ERROR			1.12	4.67			2.98	6.04	19.41	8.43	1.40
WIG 42 0-15	20049	285.65	6.11	22.25	990.63	4.65	19.01	14.13	340.98	19.43	6.26
	±1σ	47.06	0.74	3.29	70.38	0.99	1.96	3.40	12.26	5.45	0.90
WIG 42 15-30	20050	0.13	7.38	24.08	22.07	1.17	20.65	23.76	424.73	32.20	7.69
	±1σ	0.60	0.85	3.52	1.77	0.82	2.27	4.88	14.99	7.67	1.10
WEIGHTED MEAN			6.79	23.23			19.89	19.29	385.84	26.27	7.03
ERROR			1.18	5.00			3.13	6.30	20.30	9.95	1.49
WIG 43 0-5	20042	353.31	5.46	16.49	798.50	11.43	17.47	16.03	347.00	12.86	4.86
	±1σ	58.17	0.67	2.64	56.54	1.68	1.83	3.50	12.15	4.86	0.80
WIG 43 5-15	20028	354.34	6.45	24.64	1354.90	5.79	20.35	21.51	414.39	19.38	7.08
	±1σ	58.21	0.83	3.71	94.43	1.14	2.22	4.52	14.66	6.21	1.03

WIG 43 15-30	20044	-0.34	7.64	26.63	26.72	-0.07	24.84	16.17	420.73	22.74	6.95
	±1σ	-0.58	0.86	3.76	2.07	-0.77	2.42	3.98	14.72	6.35	1.02
WEIGHTED MEAN			6.94	24.51			22.34	17.84	407.91	20.23	6.69
ERROR			0.85	3.74			2.34	4.27	14.82	6.32	1.03
WIG 44 0-2	23005	685.49	5.67	6.22	818.71	5.71	16.00	43.78	296.70	7.11	12.69
	±1σ	39.20	1.59	4.63	10.78	4.57	5.93	13.08	27.99	14.29	3.00
WIG 44 2-5	20043	464.73	4.10	11.13	1627.09	20.34	12.74	13.21	297.53	15.22	5.40
	±1σ	76.32	0.59	2.17	113.28	2.77	1.57	3.12	10.84	4.70	0.79
WIG 44 5-10	10051	505.68	7.96	19.56	1416.22	3.75	18.37	33.52	442.70	21.84	8.15
	±1σ	80.23	0.84	2.94	98.92	0.78	2.62	6.80	18.15	7.30	1.46
WIG 44 10-15	10048	18.98	7.14	20.96	244.17	1.84	18.03	36.48	378.16	21.10	6.50
	±1σ	3.09	0.60	2.24	17.07	0.74	2.24	5.83	15.46	6.53	1.24
WIG 44 15-20	10049	6.82	6.78	22.52	44.99	0.36	21.84	20.56	384.03	20.53	6.23
	±1σ	1.25	0.58	2.17	3.28	0.73	2.26	5.59	15.47	6.15	1.19
WIG 44 20-30	10050	0.99	8.37	24.01	7.46	-0.78	21.16	27.75	420.37	16.29	5.82
	±1σ	0.66	0.70	2.67	0.99	-0.89	2.77	6.89	18.19	7.30	1.41

WEIGHTED MEAN			7.47	20.89			19.74	29.07	401.27	18.35	6.85
ERROR			0.70	2.56			2.60	6.44	17.01	6.95	1.35
WIG 45 0-2	13008	397.15	4.16	9.97	699.33	-1.33	18.99	12.90	257.80	40.41	7.52
	±1σ	17.11	1.08	3.39	8.19	-2.23	4.20	9.09	23.75	9.27	2.18
WIG 45 2-5	13009	457.16	3.94	11.76	1465.93	22.80	12.65	20.64	215.50	28.72	6.78
	±1σ	19.65	1.01	2.98	15.39	6.69	3.83	8.01	19.88	9.01	1.96
WIG 45 5-10	20035	721.96	5.18	8.41	2274.49	9.79	14.94	15.42	268.54	10.89	4.29
	±1σ	118.55	0.64	1.81	158.36	1.55	1.55	3.12	9.63	4.09	0.68
WIG 45 10-15	20034	68.05	5.54	17.76	460.44	2.53	16.86	19.22	296.40	14.05	4.66
	±1σ	11.23	0.64	2.58	32.32	0.87	1.70	3.69	10.45	4.43	0.73
WIG 45 15-20	20036	0.05	6.63	21.69	47.08	0.17	20.47	20.76	351.21	17.20	5.81
	±1σ	0.60	0.73	3.04	3.46	0.80	1.97	3.97	12.13	4.84	0.82
WIG 45 20-30	20031	0.22	6.88	22.82	4.18	0.20	20.16	20.82	382.63	15.12	6.59
	±1σ	0.59	0.77	3.22	0.80	0.80	2.02	4.11	12.97	5.24	0.93
WEIGHTED MEAN			5.97	17.92			18.13	19.31	324.53	16.91	5.82
ERROR			0.74	2.91			2.09	4.30	12.72	5.25	0.97

WIG 51 0-15	10044	410.12	5.36	20.22	1265.87	8.67	16.18	27.55	323.91	15.35	5.52
	±1σ	64.97	0.68	2.52	86.91	1.05	2.26	5.91	14.51	6.22	1.19
WIG 51 15-30	20055	0.11	7.32	29.82	7.93	0.41	21.47	24.04	392.95	23.77	6.40
	±1σ	0.60	0.83	4.11	0.98	0.82	2.24	4.72	13.91	6.47	0.98
WEIGHTED MEAN			6.44	25.50			19.09	25.62	361.88	19.98	6.01
ERROR			1.09	5.01			3.16	7.36	19.92	8.96	1.51
WIG 52 0-15	20047	335.19	7.51	22.42	1194.34	8.04	25.59	30.93	514.95	24.78	8.01
	±1σ	55.19	0.99	3.80	84.57	1.33	2.76	6.06	18.13	7.99	1.25
WIG 52 15-30	20056	-0.15	7.29	23.54	25.69	1.46	21.88	14.35	342.32	12.70	6.53
	±1σ	-0.58	0.80	3.31	2.02	0.73	2.10	3.47	12.38	5.02	0.92
WEIGHTED MEAN			7.39	23.00			23.66	22.32	425.37	18.51	7.24
ERROR			1.26	4.96			3.40	6.78	21.44	9.19	1.52
WIG 53 0-5	13005	414.58	6.96	25.16	966.78	7.77	14.64	13.32	315.09	34.77	7.89
	±1σ	17.83	1.20	3.62	10.55	2.97	4.50	9.95	28.28	10.91	2.35
WIG 53 5-15	20053	309.43	6.62	23.52	1105.46	4.06	16.68	13.04	334.06	22.52	4.92
	±1σ	50.82	0.79	3.39	76.85	1.04	1.88	3.38	12.37	5.95	0.85

WIG 53 15-30	20054	2.48	7.84	26.07	28.81	0.40	22.92	16.78	397.68	22.53	7.72
	±1σ	0.76	0.89	3.71	2.21	0.83	2.35	4.07	14.41	6.51	1.08
WEIGHTED MEAN			7.24	24.92			19.38	14.84	361.82	24.00	6.60
ERROR			0.87	3.63			2.33	4.29	14.69	6.65	1.09
WIG 54 0-15	10045	390.29	5.29	19.96	1308.47	8.02	16.67	12.55	302.31	8.55	4.82
	±1σ	61.91	0.63	2.29	91.15	0.94	2.08	5.18	13.60	5.70	1.08
WIG 54 15-30	20046	-0.35	7.69	26.81	28.20	-0.08	25.01	16.28	423.60	22.90	7.00
	±1σ	-0.60	0.87	3.78	2.16	-0.82	2.43	4.01	14.82	6.39	1.03
WEIGHTED MEAN			6.57	23.61			21.11	14.54	366.87	16.19	5.98
ERROR			1.13	4.72			3.35	6.65	20.92	8.92	1.54
WIG 55 0-15	10046	198.38	8.69	21.09	862.07	9.45	22.25	25.38	408.81	16.57	7.23
	±1σ	31.47	0.77	2.83	59.65	1.06	2.66	6.67	17.46	7.60	1.39
WIG 55 15-30	20057	169.47	8.11	27.34	504.72	2.85	22.74	27.96	421.10	27.10	8.95
	±1σ	27.89	0.91	3.86	35.50	0.88	2.29	5.16	14.60	6.75	1.11
WEIGHTED MEAN			8.39	24.27			22.50	26.70	415.08	21.94	8.11
ERROR			1.25	5.05			3.59	8.55	23.24	10.42	1.81

WIG 61 0-15	20030	428.17	5.23	18.26	1397.75	5.31	14.65	18.23	300.15	11.88	5.14
	±1σ	70.48	0.67	2.83	98.87	1.05	1.69	3.69	11.01	4.65	0.80
WIG 61 15-30	20058	4.92	6.98	24.98	66.59	0.19	22.24	27.65	419.08	32.42	6.72
	±1σ	1.05	0.83	3.63	4.80	0.88	2.35	5.23	14.65	7.41	1.01
WEIGHTED MEAN			6.12	21.70			18.53	23.05	360.98	22.39	5.95
ERROR			1.12	4.84			3.06	6.77	19.31	9.32	1.36
WIG 62 0-15	20059	223.87	5.04	17.21	890.95	4.74	18.54	19.65	360.02	22.97	6.91
	±1σ	36.94	0.64	2.65	63.77	0.96	1.84	3.83	12.16	5.42	0.88
WIG 62 15-30	20060	0.08	6.72	25.47	24.99	2.10	22.30	21.57	417.21	26.04	7.93
	±1σ	0.61	0.79	3.62	1.96	0.82	2.28	4.47	14.54	6.80	1.07
WEIGHTED MEAN			5.91	21.47			20.48	20.64	389.53	24.56	7.44
ERROR			1.07	4.73			3.07	6.15	19.83	9.13	1.45
WIG 63 0-5	20071	334.55	3.85	2.44	1119.17	16.93	12.38	15.59	294.01	19.82	5.70
	±1σ	54.96	0.53	1.54	77.94	2.36	1.47	3.20	10.29	4.81	0.77
WIG 63 5-15	10078	424.79	6.12	21.16	1311.76	5.13	15.39	18.55	347.86	22.08	7.63
	±1σ	67.33	0.65	2.40	90.67	0.88	2.17	5.49	14.40	6.24	1.32

WIG 63 15-30	10079	1.83	7.34	25.10	29.99	1.22	21.55	30.60	422.50	33.53	8.82
	±1σ	0.70	0.67	2.60	2.27	0.82	2.73	6.81	17.80	8.14	1.53
WEIGHTED MEAN			6.47	20.75			18.30	24.64	380.80	27.95	8.01
ERROR			0.67	2.50			2.48	6.19	16.30	7.33	1.42
WIG 64 0-15	20040	499.71	4.79	17.32	1486.25	9.48	15.83	22.97	304.28	23.79	5.12
	±1σ	82.15	0.65	2.73	104.24	1.48	1.76	4.26	11.06	5.56	0.80
WIG 64 15-30	10077	12.03	7.53	27.09	74.92	1.73	20.92	27.47	403.65	35.93	8.58
	±1σ	2.03	0.66	2.52	5.29	0.79	2.48	6.58	16.76	8.24	1.47
WEIGHTED MEAN			6.30	22.70			18.63	25.45	358.99	30.48	7.03
ERROR			0.96	3.82			3.22	8.33	21.32	10.54	1.80
WIG 65 0-15	20029	304.72	5.44	20.21	1013.53	8.09	17.66	18.67	365.67	30.40	6.97
	±1σ	50.12	0.74	3.22	71.19	1.34	2.10	4.20	13.64	6.95	1.02
WIG 65 15-30	20061	9.45	6.90	24.93	70.73	0.65	20.24	15.45	379.11	31.25	8.69
	±1σ	1.70	0.81	3.59	5.06	0.84	2.21	3.91	13.95	7.27	1.12
WEIGHTED MEAN			6.23	22.76			19.05	16.93	372.94	30.86	7.90

ERROR			1.14	5.02			3.16	5.91	20.20	10.42	1.58

WIGTOWN BAY COMPILATION Bq m^{-2}											
			^{241}Am	**^{208}Tl**	**^{214}Bi**	**^{137}Cs**	**^{134}Cs**	**^{228}Ac**	**^{228}Ac**	**^{40}K**	**^{214}Bi**	**^{208}Tl**
		Filename "GSP"	**59.5 / keV**	**583**	**609**	**662**	**796**	**911**	**969**	**1462**	**1764**	**2615**
WIG 01 0-2CM		13006	4658.3	176.1	926.3	8226.5	-2.4	386.7	496.5	9727.9	934.7	110.4
		±1σ	204.4	56.2	168.0	114.6	-45.9	235.1	488.8	945.4	504.0	99.6
WIG 01 2-5CM		10057	9032.8	196.3	683.2	28122.5	538.4	565.5	671.7	13594.3	765.6	199.6
		±1σ	1433.0	26.2	98.6	1960.6	42.1	87.7	220.1	588.8	247.6	44.7
WIG 01 5-10CM		20021	22924.6	428.5	1129.7	81689.1	317.4	1102.4	1341.6	26347.0	1549.9	301.5
		±1σ	3776.9	54.3	194.2	5811.2	51.8	129.7	276.3	912.3	411.0	60.5
WIG 01 10-15CM		20022	6206.1	502.8	1677.3	24807.8	-13.3	1526.6	1763.8	27993.7	1309.7	427.9
		±1σ	1024.0	57.8	242.5	1770.9	-35.6	151.5	331.4	961.2	407.0	64.7
WIG 01 15-20CM		20023	78.0	366.4	1370.9	2262.3	85.2	1086.3	1441.5	22459.4	1488.1	354.9
		±1σ	24.4	41.8	192.0	163.7	27.4	112.2	263.1	757.3	353.9	51.3
WIG 01 20-30CM		20024	35.2	1188.5	4141.9	1159.3	78.9	3429.9	4494.6	63992.5	3001.1	967.7

		±1σ	61.4	132.9	582.4	115.1	81.3	349.7	820.0	2234.2	934.0	155.9
	TOT		38276.7	2682.6	9002.9	138041.0	1006.6	7710.6	9713.2	154386.9	8114.4	2251.7
	ERR		4167.9	162.5	694.4	6386.7	114.4	427.0	988.1	2769.1	1180.5	191.8
WIG 11 0-15CM		10060	46599.3	1517.4	4272.2	142688.0	753.8	2816.8	1922.1	62223.1	990.2	1034.9
		±1σ	7396.0	136.0	495.2	9999.4	103.5	399.7	928.3	2835.3	1053.9	222.0
WIG 11 15-30CM		10065	200.4	1523.2	4512.7	3889.2	134.0	2576.7	2569.0	59851.8	2689.7	870.5
		±1σ	95.5	143.7	551.5	294.6	113.1	531.1	1240.7	3291.5	1363.8	254.5
	TOT		46799.7	3040.6	8785.0	146577.2	887.7	5393.5	4491.1	122074.9	3680.0	1905.4
	ERR		7396.6	197.9	741.2	10003.7	153.3	664.7	1549.5	4344.3	1723.5	337.8
WIG 12 0-15CM		20048	56530.5	1763.8	4710.5	195983.0	1221.6	5061.3	5087.5	100456.0	8637.2	1584.4
		±1σ	9309.4	216.7	779.4	13882.9	209.1	543.3	1076.9	3539.7	1860.7	250.8
WIG 12 15-30CM		10064	144.3	1491.3	5129.7	4392.0	8.2	3807.6	2858.9	61860.2	3475.7	1301.6
		±1σ	80.8	126.4	492.3	322.7	99.4	456.5	1021.5	2971.9	1215.0	252.6
	TOT		56674.8	3255.0	9840.3	200375.0	1229.8	8868.9	7946.4	162316.2	12112.9	2886.0

	ERR		9309.8	250.8	921.8	13886.6	231.5	709.6	1484.3	4621.9	2222.2	355.9
WIG 13 0-5CM		10061	11898.8	320.2	1201.3	27648.0	462.9	811.6	936.1	15662.3	1441.8	233.8
		±1σ	1887.1	34.5	128.9	1923.1	40.5	106.4	247.6	719.4	339.9	54.5
WIG 13 5-15CM		10062	32384.2	877.8	3293.4	75611.1	1269.1	2225.1	2566.3	42938.1	3952.8	640.9
		±1σ	5135.0	94.6	353.3	5248.4	111.1	291.6	678.9	1972.3	931.8	149.4
WIG 13 15-30CM		10063	-113.4	1702.6	5551.9	2466.8	353.9	3937.3	2772.5	72207.4	3457.0	1439.1
		±1σ	-95.8	152.7	579.7	201.8	113.2	533.9	1258.3	3590.6	1427.6	294.5
	TOT		44169.6	2900.5	10046.6	105725.9	2085.9	6974.0	6274.9	130807.8	8851.6	2313.8
	ERR		5471.6	182.9	691.0	5593.2	163.7	617.6	1451.0	4159.3	1738.4	334.7
WIG 14 0-2CM		23004	6338.9	191.6	371.1	7061.1	62.7	433.2	1012.0	8666.0	244.9	467.3
		±1σ	361.8	33.1	95.3	90.9	43.6	118.8	296.5	726.1	331.5	78.0
WIG 14 2-5CM		20032	10186.5	306.9	590.7	33657.5	647.4	802.2	818.8	15953.1	1119.7	257.4
		±1σ	1675.4	37.0	115.6	2366.1	86.5	90.0	178.6	577.5	274.9	41.2
WIG 14 5-10CM		20033	29128.6	531.3	1840.8	96839.2	252.7	1544.4	1412.5	29750.7	1633.6	544.3
		±1σ	4798.7	66.5	277.8	6887.5	50.7	162.1	307.3	1050.0	478.1	77.5

WIG 14 10-15CM		10052	5498.5	528.0	1485.2	27603.7	75.2	1234.4	2346.0	28086.1	1232.5	591.3
		±1σ	874.1	48.2	178.2	1940.2	33.9	171.9	435.9	1177.4	467.8	102.7
WIG 14 15-20CM		10053	131.5	587.6	1932.3	4356.5	74.4	2081.1	2416.9	35793.4	1354.8	604.9
		±1σ	40.8	54.2	208.8	311.4	40.2	217.4	535.3	1471.1	548.3	114.0
WIG 14 20-30CM		10054	39.7	1217.7	4177.4	1476.8	-42.2	3670.3	6393.3	75431.2	6351.5	1564.0
		±1σ	72.9	116.0	442.6	138.1	-89.3	457.6	1139.4	3132.1	1443.9	265.4
	TOT		44984.8	3171.5	10026.3	163933.7	1007.4	9332.3	13387.4	185014.5	11692.1	3561.9
	ERR		5158.1	156.5	601.5	7544.3	144.3	566.2	1378.8	3846.6	1705.4	318.9
WIG 15 0-2CM		13004	4088.8	173.0	696.7	8865.4	34.1	952.8	1294.5	12205.0	841.1	233.8
		±1σ	179.6	45.5	140.6	110.8	35.8	175.9	366.7	1096.0	461.7	90.4
WIG 15 2-5CM		10037	12347.2	371.7	1483.1	21528.6	133.1	1152.7	1399.7	23060.5	1236.2	351.5
		±1σ	1960.8	39.1	152.3	1516.9	31.2	141.3	356.6	968.3	406.5	69.5
WIG 15 5-10CM		10038	14606.9	405.2	1461.9	53884.5	728.7	1262.7	2283.4	28037.3	2022.1	571.8
		±1σ	2320.3	54.0	203.8	3800.6	63.6	181.4	460.6	1202.6	543.0	103.3

WIG 15 10-15CM		10039	21189.8	595.7	1763.0	91391.7	178.8	1270.7	2565.0	30799.7	2073.0	591.2
		±1σ	3362.5	62.2	229.8	6391.8	40.2	195.7	512.9	1307.2	557.1	108.6
WIG 15 15-20CM		10040	32412.2	440.4	1563.6	84112.1	94.1	1327.4	1729.0	29402.1	1550.5	474.8
		±1σ	5151.3	54.8	205.4	5981.6	35.5	172.5	430.1	1207.1	483.0	91.0
WIG 15 20-30CM		10041	7775.4	1541.1	5014.3	28638.0	317.3	4343.1	5210.4	71468.7	4536.9	964.3
		±1σ	1238.3	126.2	482.2	2006.5	91.5	474.6	1187.4	3058.9	1312.1	224.3
	TOT		92420.3	3527.2	11982.6	288420.3	1486.1	10309.4	14482.0	194973.3	12259.8	3187.4
	ERR		6974.0	171.2	641.9	9870.1	132.5	614.1	1527.0	4013.4	1714.2	306.6
WIG 21 0-15CM		20038	40233.0	1202.5	3408.7	127602.0	1094.1	3730.5	4753.4	71275.8	3802.7	874.5
		±1σ	6627.9	147.2	552.2	9062.8	168.2	387.7	893.6	2477.4	1098.8	161.4
WIG 21 15-30CM		10073	325.0	1901.4	6724.9	7296.8	264.7	5544.3	8265.1	101772.0	6516.9	2616.6
		±1σ	115.7	164.1	642.4	530.7	123.8	641.2	1699.1	4304.1	1914.7	429.5
	TOT		40558.0	3103.8	10133.6	134898.8	1358.8	9274.9	13018.5	173047.8	10319.6	3491.1

	ERR		6628.9	220.4	847.1	9078.3	208.8	749.2	1919.8	4966.2	2207.6	458.8
WIG 22 0-15CM		10066	44678.4	1339.1	5617.9	144329.0	1028.8	2990.7	1358.1	59145.3	1936.1	976.5
		±1σ	7088.4	145.4	549.2	10066.2	123.1	438.5	1044.5	2947.6	1186.3	242.9
WIG 22 15-30CM		10067	105.3	1941.5	7947.5	4014.3	167.3	4576.7	9485.0	108290.0	7293.0	1685.7
		±1σ	110.5	172.9	685.5	306.3	135.9	615.5	1563.7	4418.8	1974.8	340.0
	TOT		44783.7	3280.6	13565.4	148343.3	1196.1	7567.4	10843.1	167435.3	9229.0	2662.2
	ERR		7089.2	225.9	878.4	10070.9	183.3	755.7	1880.5	5311.7	2303.7	417.8
WIG 23 0-5CM		10056	11749.5	484.2	1583.8	35388.7	702.4	914.2	1223.2	25590.0	1068.2	417.7
		±1σ	1865.7	47.3	176.9	2485.6	59.9	160.4	399.9	1094.3	454.5	80.6
WIG 23 5-15CM		10068	21083.1	1043.5	3196.3	90347.1	294.5	2524.9	3338.7	51560.7	4823.8	900.6
		±1σ	3350.2	96.1	359.6	6381.6	64.6	294.9	688.8	2120.2	1003.8	160.6
WIG 23 15-30CM		10069	701.1	1880.4	6540.2	8973.5	231.2	5651.0	7992.5	97854.6	7615.4	1825.6
		±1σ	151.1	159.0	608.3	642.4	121.5	580.1	1360.4	4029.8	1785.4	321.7
	TOT		33533.7	3408.1	11320.3	134709.3	1228.1	9090.2	12554.3	175005.3	13507.5	3143.9

	ERR		3837.7	191.8	728.4	6878.6	150.1	670.2	1576.4	4683.1	2098.0	368.5
WIG 24 0-15CM		10070	49505.6	1058.4	4201.2	150733.0	724.4	3298.9	2883.5	66093.3	1455.2	1262.1
		±1σ	7852.5	124.3	464.2	10502.4	97.0	404.3	1012.5	2740.5	1110.5	225.2
WIG 24 15-30CM		10071	6995.3	1809.8	7286.2	27973.2	309.1	5734.2	6641.6	101175.0	8390.8	2336.8
		±1σ	1116.9	165.8	630.3	1952.1	122.7	636.2	1612.7	4171.4	1990.6	390.1
	TOT		56500.9	2868.2	11487.3	178706.2	1033.4	9033.1	9525.1	167268.3	9846.0	3598.9
	ERR		7931.5	207.2	782.8	10682.3	156.4	753.7	1904.2	4991.1	2279.4	450.4
WIG 25 0-15CM		10055	50397.3	1587.1	4902.9	199137.0	1394.3	2162.0	7088.4	79254.9	4050.9	1582.4
		±1σ	8002.9	159.6	586.5	14012.1	145.6	518.1	1316.1	3392.1	1449.1	282.8
WIG 25 15-30CM		10072	668.4	2006.3	6992.4	9061.6	83.3	6921.2	7803.6	106734.0	8398.3	1875.1
		±1σ	160.8	178.2	708.7	663.6	143.5	710.0	1804.1	4577.9	2224.7	390.7
	TOT		51065.7	3593.4	11895.3	208198.6	1477.7	9083.2	14892.0	185988.9	12449.2	3457.5
	ERR		8004.5	239.2	919.9	14027.8	204.4	878.9	2233.1	5697.7	2655.1	482.3
WIG 31 0-15CM		10074	41891.5	1529.6	4896.8	129463.0	1011.6	4490.1	4499.0	79198.8	4522.0	1519.4

		±1σ	6651.2	138.2	510.1	9098.1	117.5	462.2	1160.1	3195.3	1358.0	260.8
WIG 31 15-30CM		10075	369.3	2142.4	6812.5	5445.0	-50.0	6681.5	7625.2	106711.0	9668.5	1955.2
		±1σ	119.9	168.4	637.6	407.0	-130.7	659.4	1631.7	4409.3	2159.0	355.8
	TOT		42260.8	3672.0	11709.3	134908.0	961.6	11171.6	12124.2	185909.8	14190.5	3474.6
	ERR		6652.3	217.9	816.6	9107.2	175.7	805.2	2002.0	5445.3	2550.5	441.1
WIG 32 0-15CM		20075	35983.8	1336.6	2756.2	144568.0	778.1	3532.0	3977.1	77412.4	3864.2	1216.9
		±1σ	5918.4	171.8	560.2	10129.2	156.6	434.1	900.5	2897.5	1300.2	210.4
WIG 32 15-30CM		10080	127.1	2333.2	8278.8	9315.2	236.9	6616.2	4335.9	123643.0	8661.0	2597.0
		±1σ	120.6	184.0	717.8	678.0	136.8	720.5	1807.3	4954.1	2262.5	438.1
	TOT		36110.9	3669.8	11035.0	153883.2	1015.1	10148.2	8312.9	201055.4	12525.2	3813.9
	ERR		5919.6	251.7	910.5	10151.9	208.0	841.2	2019.2	5739.2	2609.4	486.0
WIG 33 0-5CM		20076	8046.2	269.5	512.4	20823.9	204.8	701.0	873.4	17190.3	1033.6	307.6
		±1σ	1323.4	35.3	113.7	1460.3	38.0	93.8	198.6	645.0	306.8	48.7
WIG 33 5-15CM		10047	32602.3	872.4	3157.3	119521.0	677.4	2450.8	3272.4	55653.9	4494.3	1132.7
		±1σ	5169.6	111.2	417.9	8282.9	89.7	374.5	938.8	2457.3	1140.8	208.9

WIG 33 15-30CM		20078	-30.5	1838.8	6066.3	8979.9	-63.7	5146.8	5389.5	102970.0	7711.5	1875.1
		±1σ	-109.6	213.0	889.1	653.1	-141.7	562.1	1146.2	3713.7	1817.0	274.9
	TOT		40618.0	2980.7	9736.0	149324.8	818.5	8298.6	9535.3	175814.2	13239.3	3315.4
	ERR		5337.4	242.8	989.0	8435.9	172.0	681.9	1494.8	4499.5	2167.3	348.7
WIG 34 0-15CM		20041	50556.8	1294.9	4698.9	169047.0	888.6	3868.5	4024.7	80075.8	3463.5	1376.6
		±1σ	8326.8	161.4	703.9	11993.4	156.8	415.2	837.1	2787.5	1146.1	196.1
WIG 34 15-30CM		20077	-272.6	1454.1	6393.6	2749.5	-16.0	5356.9	2990.6	94908.4	6715.5	1765.3
		±1σ	-114.7	177.2	903.0	239.9	-128.7	549.8	865.3	3427.9	1672.4	248.6
	TOT		50284.3	2749.0	11092.5	171796.5	872.6	9225.4	7015.3	174984.2	10178.9	3142.0
	ERR		8327.6	239.7	1145.0	11995.8	202.9	689.0	1203.9	4418.2	2027.4	316.6
WIG 35 0-15CM		20039	70950.3	1485.9	5930.0	256630.0	672.0	4922.4	5520.8	90975.8	6214.8	1718.5
		±1σ	11650.6	189.6	868.6	17855.2	146.7	500.5	1068.7	3175.6	1498.7	234.7
WIG 35 15-30CM		20074	302.9	1742.3	6589.8	6942.1	412.0	6200.8	5405.0	103874.0	3710.1	2293.8
		±1σ	121.7	209.1	951.4	513.7	149.9	629.9	1167.5	3778.5	1552.1	300.7

	TOT		71253.2	3228.2	12519.7	263572.1	1084.0	11123.2	10925.8	194849.8	9924.9	4012.3
	ERR		11651.2	282.3	1288.3	17862.6	209.7	804.6	1582.8	4935.7	2157.6	381.5
WIG 41 0-15CM		20051	39570.4	1220.2	3996.6	133088.0	494.1	3730.6	4001.4	70967.6	2902.2	1401.4
		±1σ	6507.5	150.6	611.0	9343.3	117.6	400.4	819.8	2529.9	1077.8	192.9
WIG 41 15-30CM		20052	1677.7	1799.6	6114.9	11858.7	396.4	5185.3	5421.0	105374.0	6348.9	1705.8
		±1σ	300.2	209.6	889.0	856.1	140.6	559.5	1129.8	3697.7	1619.2	260.4
	TOT		41248.1	3019.7	10111.5	144946.7	890.5	8915.9	9422.4	176341.6	9251.1	3107.2
	ERR		6514.4	258.1	1078.7	9382.5	183.3	688.0	1395.9	4480.3	1945.1	324.0
WIG 42 0-15CM		20049	39949.4	1393.6	5075.9	138544.0	650.5	4335.6	3222.7	77773.0	4431.1	1428.8
		±1σ	6582.1	169.4	749.4	9842.4	138.7	447.0	775.2	2797.3	1243.5	205.6
WIG 42 15-30CM		20050	23.1	1940.4	6335.0	4029.2	213.7	5433.2	6250.9	111738.0	8470.3	2024.0
		±1σ	109.5	224.8	926.1	323.1	150.6	596.8	1283.7	3943.9	2018.3	289.4
	TOT		39972.5	3334.0	11410.8	142573.2	864.2	9768.8	9473.6	189511.0	12901.4	3452.7
	ERR		6583.0	281.5	1191.4	9847.7	204.7	745.6	1499.6	4835.2	2370.6	355.0

WIG 43 0-5CM	20042	14546.2	393.8	1189.4	32874.9	470.7	1260.5	1156.1	25030.3	927.8	350.4
	±1σ	2395.0	48.6	190.4	2327.9	69.0	132.3	252.7	876.4	350.5	57.8
WIG 43 5-15CM	20028	35520.1	1000.0	3822.1	135818.0	580.7	3156.1	3335.8	64271.0	3005.2	1098.3
	±1σ	5835.1	129.2	574.9	9466.3	114.0	344.0	701.7	2274.1	963.7	159.5
WIG 43 15-30CM	20044	-62.1	2017.5	7036.6	4930.9	-13.3	6564.5	4273.5	111171.0	6009.5	1837.5
	±1σ	-107.2	227.2	992.5	381.9	-142.3	638.7	1052.8	3888.4	1676.9	270.5
TOT		50004.2	3411.4	12048.0	173623.8	1038.1	10981.1	8765.4	200472.3	9942.6	3286.2
ERR		6308.4	265.9	1162.7	9755.8	194.9	737.5	1290.2	4589.0	1965.6	319.3
WIG 44 0-2CM	23005	8391.5	150.7	165.1	10022.3	69.9	425.1	1162.8	7881.0	189.0	337.1
	±1σ	479.8	42.3	122.9	131.9	55.9	157.6	347.4	743.4	379.4	79.7
WIG 44 2-5CM	20043	9923.7	179.4	487.0	34744.0	434.4	557.4	578.1	13019.2	666.0	236.2
	±1σ	1629.8	25.9	95.1	2418.9	59.2	68.7	136.6	474.5	205.5	34.7
WIG 44 5-10CM	10051	23470.8	522.9	1285.9	65732.8	174.0	1207.4	2202.9	29095.5	1435.7	535.6
	±1σ	3723.6	55.0	193.3	4591.1	36.1	172.4	446.6	1192.7	479.5	95.7
WIG 44 10-15CM	10048	844.8	545.9	1602.9	10867.5	82.1	1378.3	2789.6	28915.8	1613.3	497.3

		$\pm 1\sigma$	137.7	46.0	171.3	759.6	32.9	171.4	445.9	1182.1	499.3	94.5
WIG 44 15-20CM		10049	313.6	519.2	1726.0	2069.6	16.5	1673.3	1575.2	29426.3	1573.3	477.1
		$\pm 1\sigma$	57.5	44.6	166.6	150.7	33.5	172.9	428.3	1185.6	471.0	91.3
WIG 44 20-30CM		10050	104.1	1394.9	4000.8	788.2	-82.2	3526.1	4624.0	70043.8	2714.8	969.4
		$\pm 1\sigma$	70.2	117.4	444.9	104.2	-94.1	460.9	1148.0	3030.7	1217.0	235.0
	TOT		43048.4	3313.0	9267.6	124224.3	694.7	8767.5	12932.5	178381.6	8192.1	3052.8
	ERR		4096.2	152.9	562.6	5249.5	137.8	575.3	1427.9	3766.8	1538.9	298.6
WIG 45 0-2CM		13008	2568.5	69.2	165.7	4522.7	-8.6	315.8	214.5	4287.2	672.1	125.1
		$\pm 1\sigma$	110.7	18.0	56.3	52.9	-14.4	69.9	151.1	394.9	154.2	36.3
WIG 45 2-5CM		13009	5279.6	131.9	394.0	16929.5	263.3	423.6	691.3	7217.3	961.9	227.1
		$\pm 1\sigma$	227.0	34.0	99.9	177.7	77.3	128.1	268.4	666.0	301.8	65.6
WIG 45 5-10CM		20035	19593.5	330.0	536.0	61728.3	265.7	952.2	983.2	17118.9	694.1	273.2
		$\pm 1\sigma$	3217.5	40.8	115.7	4297.8	42.0	98.6	199.1	613.9	260.5	43.6
WIG 45 10-15CM		20034	1972.7	337.8	1083.1	13347.0	73.4	1028.3	1172.2	18073.5	857.0	284.0
		$\pm 1\sigma$	325.4	39.0	157.4	936.8	25.2	103.6	224.8	637.2	270.4	44.2

WIG 45 15-20CM		20036	2.0	463.2	1515.8	1777.9	6.4	1430.2	1450.6	24539.1	1202.1	406.2
		$\pm1\sigma$	22.7	51.2	212.4	130.5	30.3	137.8	277.2	847.7	338.3	57.3
WIG 45 20-30CM		20031	18.1	971.6	3219.9	342.1	16.1	2845.3	2938.0	53998.7	2133.7	929.4
		$\pm1\sigma$	48.6	108.8	453.9	65.2	65.6	285.5	579.3	1829.9	739.3	130.7
	TOT		29434.3	2303.7	6914.5	98647.5	616.4	6995.4	7449.8	125234.7	6520.9	2245.0
	ERR		6703.1	199.5	687.0	18067.4	277.5	632.6	1013.2	8678.7	1476.1	302.4
WIG 51 0-15CM		10044	45364.1	1086.7	4101.6	140022.0	958.5	3282.2	5589.5	65713.0	3113.6	1120.8
		$\pm1\sigma$	7187.0	137.5	511.2	9613.2	115.8	458.6	1199.4	2943.2	1261.8	242.4
WIG 51 15-30CM		20055	18.2	1823.4	7427.6	1282.3	66.2	5348.9	5988.6	97890.7	5920.2	1593.9
		$\pm1\sigma$	97.2	207.5	1023.4	158.9	132.5	557.0	1175.5	3466.2	1610.6	243.9
	TOT		45382.3	2910.1	11529.2	141304.3	1024.7	8631.2	11578.1	163603.7	9033.9	2714.7
	ERR		7187.6	249.0	1144.0	9614.5	176.0	721.5	1679.4	4547.1	2046.0	343.9
WIG 52 0-15CM		20047	63096.7	1630.0	4867.2	224826.0	1513.6	5555.0	6714.7	111803.0	5380.2	1738.2
		$\pm1\sigma$	10390.0	215.7	824.7	15920.6	249.6	598.6	1316.0	3935.7	1734.6	270.4

WIG 52 15-30CM		20056	-22.3	1710.5	5524.5	3933.4	224.3	5134.9	3366.3	80330.8	2979.3	1533.3
		±1σ	-89.3	188.7	776.8	308.7	111.4	493.9	814.0	2905.7	1178.4	216.4
	TOT		63074.4	3340.5	10391.7	228759.4	1737.9	10689.9	10081.0	192133.8	8359.5	3271.5
	ERR		10390.4	286.6	1132.9	15923.6	273.3	776.1	1547.4	4892.2	2097.0	346.3
WIG 53 0-5CM		13005	8139.3	305.5	1104.4	18980.5	152.6	642.6	584.5	13827.7	1525.8	346.1
		±1σ	350.1	52.9	158.7	207.1	58.3	197.6	436.6	1241.1	478.7	103.0
WIG 53 5-15CM		20053	25229.0	989.4	3516.9	90131.8	330.9	2495.2	1950.9	49960.6	3367.8	735.6
		±1σ	4143.5	117.6	507.5	6266.1	84.5	281.8	505.7	1849.4	889.5	127.2
WIG 53 15-30CM		20054	281.0	1361.6	4525.2	3260.8	44.8	3978.2	2912.2	69027.4	3910.1	1339.5
		±1σ	86.0	154.1	644.3	250.3	93.9	408.1	706.5	2501.1	1129.8	187.4
	TOT		25510.0	2351.0	8042.0	93392.6	375.7	6473.4	4863.1	118988.0	7277.9	2075.1
	ERR		4144.4	193.8	820.2	6271.1	126.3	495.9	868.9	3110.6	1438.0	226.5
WIG 54 0-15CM		10045	44360.9	1094.9	4129.9	148724.0	912.0	3449.6	2597.6	62559.2	1768.9	996.6
		±1σ	7036.8	129.8	474.5	10360.1	107.4	430.2	1072.2	2814.5	1179.5	222.6

WIG 54 15-30CM		20046	-53.5	1775.6	6192.9	4311.8	-11.7	5777.4	3761.1	97841.4	5289.0	1617.2
		$\pm 1\sigma$	-92.4	200.0	873.5	331.0	-125.2	562.2	926.6	3422.2	1475.9	238.0
	TOT		44307.4	2870.5	10322.8	153035.8	900.2	9227.0	6358.7	160400.6	7057.9	2613.8
	ERR		7037.4	238.4	994.1	10365.4	165.0	707.9	1417.1	4430.8	1889.2	325.9
WIG 55 0-15CM		10046	29528.7	1963.9	4767.6	128319.0	1406.2	5028.9	5738.2	92413.7	3744.8	1635.0
		$\pm 1\sigma$	4683.8	174.3	639.2	8879.0	158.5	601.4	1506.7	3947.8	1718.9	314.8
WIG 55 15-30CM		20057	26029.4	1956.7	6597.9	77523.3	437.6	5488.2	6749.1	101640.0	6541.8	2159.7
		$\pm 1\sigma$	4284.0	219.5	932.4	5452.2	135.8	553.9	1244.4	3525.0	1629.0	267.7
	TOT		55558.1	3920.6	11365.5	205842.3	1843.8	10517.1	12487.2	194053.7	10286.7	3794.8
	ERR		6347.5	280.3	1130.4	10419.3	208.7	817.6	1954.1	5292.5	2368.1	413.3
WIG 61 0-15CM		20030	49794.0	1086.9	3796.5	162552.0	618.0	3046.1	3788.9	62394.6	2469.6	1068.9
		$\pm 1\sigma$	8196.9	139.9	588.2	11497.7	122.4	351.4	767.0	2288.2	967.2	166.3
WIG 61 15-30CM		20058	704.7	1514.6	5420.2	9539.1	27.8	4824.7	5999.9	90924.8	7034.1	1458.2
		$\pm 1\sigma$	151.0	179.1	787.0	687.4	125.5	510.0	1135.3	3178.0	1608.6	219.7

	TOT		50498.7	2601.5	9216.6	172091.1	645.8	7870.8	9788.8	153319.4	9503.7	2527.1
	ERR		8198.3	227.3	982.5	11518.2	175.3	619.3	1370.1	3916.1	1877.0	275.5
WIG 62 0-15CM		20059	28049.2	1117.9	3815.4	111629.0	594.4	4110.8	4356.9	79833.4	5094.4	1531.3
		±1σ	4628.1	141.8	588.7	7989.7	120.6	408.2	850.3	2695.8	1202.6	194.3
WIG 62 15-30CM		20060	13.2	1588.1	6022.2	3960.5	332.1	5271.7	5100.1	98632.8	6157.0	1875.4
		±1σ	96.6	186.6	854.7	311.3	129.9	538.1	1055.7	3437.2	1607.2	252.3
	TOT		28062.4	2706.0	9837.6	115589.5	926.5	9382.5	9457.0	178466.2	11251.4	3406.7
	ERR		4629.1	234.4	1037.8	7995.8	177.2	675.5	1355.6	4368.3	2007.3	318.5
WIG 63 0-5CM		20071	9098.7	239.7	152.1	30438.2	460.3	771.3	971.0	18314.8	1234.4	355.4
		±1σ	1494.8	33.1	96.2	2119.8	64.2	91.5	199.1	641.0	299.5	47.7
WIG 63 5-15CM		10078	34507.2	921.3	3185.4	106558.0	417.1	2316.5	2791.8	52353.6	3323.6	1148.7
		±1σ	5469.7	98.5	360.9	7365.2	71.1	327.3	826.1	2167.2	938.5	198.1
WIG 63 15-30CM		10079	290.9	1835.0	6277.4	4773.3	193.4	5389.6	7653.7	105686.0	8387.1	2206.8
		±1σ	110.6	168.7	650.3	360.9	130.2	682.1	1704.0	4452.1	2036.4	382.2

	TOT		43896.8	2996.0	9614.9	141769.5	1070.8	8477.4	11416.5	176354.4	12945.2	3710.8
	ERR		5671.4	198.2	750.0	7672.6	161.6	762.1	1904.1	4992.9	2262.2	433.1
WIG 64 0-15CM		20040	53266.4	956.5	3460.7	158425.0	1010.3	3163.0	4589.4	60793.2	4754.0	1023.3
		±1σ	8756.9	129.5	545.1	11111.0	157.3	351.3	851.7	2209.4	1111.5	158.9
WIG 64 15-30CM		10077	1820.7	1801.0	6476.2	11340.0	261.3	5002.0	6566.5	96500.2	8589.8	2051.4
		±1σ	306.5	157.8	603.1	800.3	118.8	594.0	1572.4	4006.3	1969.3	352.2
	TOT		55087.1	2757.5	9936.9	169765.0	1271.5	8165.0	11155.8	157293.4	13343.8	3074.7
	ERR		8762.3	204.1	812.9	11139.8	197.1	690.1	1788.3	4575.2	2261.3	386.4
WIG 65 0-15CM		20029	46310.8	1235.5	4586.9	154037.0	1229.0	4007.8	4236.0	82982.0	6898.6	1582.2
		±1σ	7616.6	168.9	729.8	10819.4	203.8	477.1	953.9	3094.6	1576.1	231.8
WIG 65 15-30CM**		20061	1475.9	1681.9	6080.7	11048.3	101.4	4936.9	3769.6	92473.2	7621.5	2120.2
		±1σ	265.7	196.8	875.9	791.0	131.6	538.3	954.2	3402.3	1772.3	273.2
	TOT		47786.7	2917.5	10667.6	165085.3	1330.4	8944.7	8005.6	175455.2	14520.1	3702.4
	ERR		7621.3	259.3	1140.1	10848.3	242.7	719.3	1349.2	4599.1	2371.7	358.2

Longbridgemuir Calibration Site / Bq kg^{-1}			
		^{137}Cs	^{134}Cs
Sample Name	**File Name**	**662 keV**	**794 keV**
LONG 13 0-15	10002	228.194	12.6594
	±1σ	15.3813	1.5023
LONG 13 15-30	10003	14.0249	0.2236
	±1σ	1.4804	1.1021
LONG 13 30-45	10004	242.428	13.5191
	±1σ	16.2985	1.6043
LONG 23 0-15	10005	209.584	11.5355
	±1σ	14.1877	1.3689
LONG 23 15-30	10006	6.0601	1.3157
	±1σ	1.2701	1.1803
LONG 23 30-45	10008	0.1678	1.5391
	±1σ	1.1109	1.2084
LONG 33 0-5	10009	330.791	18.0605
	±1σ	22.1474	1.9243
LONG 33 5-10	10010	328.298	17.9138
	±1σ	21.9863	1.9086
LONG 33 10-15	10011	300.389	16.2716
	±1σ	20.1875	1.7337
LONG 33 15-30	10012	15.7214	-0.1258
	±1σ	1.5954	-1.2397
LONG 33 30-45	10014	12.8379	0.2848
	±1σ	1.4315	1.1904
LONG 34 15-30	10016	4.6538	1.6044

	±1σ	1.1272	1.0655
LONG 34 30-45	10017	6.1312	0.053691
	±1σ	1.2178	1.1779
LONG 43 0-15	10018	203.114	13.2869
	±1σ	13.6692	1.5916
LONG 43 15-30	10019	10.2614	0.8992
	±1σ	1.2516	1.02
LONG 43 30-45	10020	14.2069	1.5179
	±1σ	1.4863	1.1654
LONG 44 0-5	10021	433.422	22.2628
	±1σ	28.877	2.2734
LONG 44 5-10	10022	257.726	10.8682
	±1σ	17.2815	1.6652
LONG 44 10-15	10023	65.1837	0.869
	±1σ	4.5886	1.3357
LONG 44 15-30	10024	24.743	0.9426
	±1σ	2.1048	1.2362
LONG 44 30-45	10025	13.6947	0.8731
	±1σ	1.467	1.1649
LONG 63 0-5	10026	740.011	37.0985
	±1σ	49.4571	2.9549
LONG 63 5-10	10027	213.456	9.114
	±1σ	14.4128	1.4485
LONG 63 10-15	10028	43.1643	3.6944
	±1σ	3.2509	1.4205
LONG 63 15-30	10029	8.6639	1.1688
	±1σ	1.2737	1.094

LONG 63 30-45	10030	10.7221	0.7589
	±1σ	1.4273	1.2788
LONG 64 0-15	10032	520.235	26.8877
	±1σ	34.6413	2.4709
LONG 64 15-30	10033	36.7234	1.9009
	±1σ	2.7518	1.1746
LONG 64 30-45	10034	30.8402	1.8796
	±1σ	2.4223	1.1981
LONG 24 0-5	20002	760.687	37.746
	±1σ	50.4063	4.9774
LONG 24 10-15	20003	10.5138	1.0156
	±1σ	1.0674	1.0348
LONG 24 15-30	20004	8.93	0.9819
	±1σ	0.8748	0.8326
LONG 24 30-45	20005	5.8163	0.7253
	±1σ	0.8214	0.9937
LONG 24 5-10	20006	48.227	1.062
	±1σ	3.3595	0.9764
LONG 14 0-5	20007	488.519	24.9636
	±1σ	32.0108	3.5268
LONG 14 5-10	20008	188.989	9.522
	±1σ	12.5684	1.6705
LONG 14 10-15	23006	62.1316	2.3266
	±1σ	3.9107	3.5784
LONG 14 15-30	20009	34.4133	1.7832
	±1σ	2.4696	1.0036
LONG 14 30-45	20011	22.6867	0.2829

	±1σ	1.7263	0.9843
LONG 53 0-15	20012	327.056	16.5139
	±1σ	21.9146	2.3357
LONG 53 15-30	20013	18.9719	-0.5013
	±1σ	1.5008	-1.0011
LONG 53 30-45	20014	24.0344	1.7978
	±1σ	1.8711	1.2325
LONG 54 0-5	23007	852.253	36.6666
	±1σ	11.2875	18.8303
LONG 54 5-10	20016	171.313	8.8712
	±1σ	11.3351	2.1248
LONG 54 10-15	23008	84.5355	2.5587
	±1σ	3.8079	3.5696
LONG 54 15-30	20017	31.8033	2.8089
	±1σ	2.3086	1.0642
LONG 54 30-45	20018	35.5547	-0.2195
	±1σ	2.5657	-1.1399

Longbridgemuir Calibration Site / Bq m^{-2}			
Sample Name	**File Name**	**^{137}Cs 662 keV**	**^{134}Cs 794 keV**
LONG 13 0-15	10002	7033.72	390.207
	±1σ	474.104	46.3065
LONG 13 15-30	10003	335.439	5.3485
	±1σ	35.4062	26.3599
LONG 13 30-45	10004	432.277	24.1062
	±1σ	29.0621	2.86071
LONG 13 TOTAL		**7801.436**	**419.6617**
ERROR		**476.3117**	**53.36028**
LONG 23 0-15	10005	6690.02	368.219
	±1σ	452.879	43.697
LONG 23 15-30	10006	124.785	27.0921
	±1σ	26.1538	24.3046
LONG 23 30-45	10008	3.3471	30.6968
	±1σ	22.1559	24.1007
LONG 23		**6818.152**	**426.0079**
ERROR		**454.1743**	**55.50662**
LONG 33 0-5	10009	3526.04	192.515
	±1σ	236.079	20.5114
LONG 33 5-10	10010	4071.98	222.19
	±1σ	272.703	23.6732
LONG 33 10-15	10011	3378.9	183.029
	±1σ	227.077	19.5008
LONG 33 15-30	10012	316.644	-2.5334
	±1σ	32.1335	-24.97
LONG 33 30-45	10014	271.761	6.0291
	±1σ	30.3034	25.1985
LONG 33 TOTAL		**11565.33**	**601.2297**

ERROR		**428.5033**	**51.18481**
LONG 43 0-15	10018	7208.33	471.541
	±1σ	485.109	56.4861
LONG 43 15-30	10019	266.4	23.3438
	±1σ	32.4924	26.4819
LONG 43 30-45	10020	214.277	22.894
	±1σ	22.4179	17.5777
LONG 43 TOTAL		**7689.007**	**517.7788**
ERROR		**486.7125**	**64.81471**
LONG 53 0-15	20012	11331.2	572.143
	±1σ	759.253	80.9244
LONG 53 15-30	20013	416.29	-10.999
	±1σ	32.9312	-21.968
LONG 53 30-45	20014	416.348	31.143
	±1σ	32.4128	21.3503
LONG 53 TOTAL		**12163.84**	**592.287**
ERROR		**760.6577**	**86.52853**
LONG 63 0-5	10026	8229.94	412.586
	±1σ	550.031	32.8626
LONG 63 5-10	10027	2721.5	116.201
	±1σ	183.76	18.468
LONG 63 10-15	10028	402.781	34.4739
	±1σ	30.3354	13.2555
LONG 63 15-30	10029	164.092	22.1366
	±1σ	24.123	20.7199
LONG 63 30-45	10030	175.338	12.4099
	±1σ	23.3403	20.9118
LONG 63 TOTAL		**11693.65**	**597.8074**
ERROR		**581.6775**	**49.63208**
LONG 14 0-5	20007	4062.05	207.574

	±1σ	266.171	29.3259
LONG 14 5-10	20008	2182.58	109.967
	±1σ	145.149	19.2926
LONG 14 10-15	23006	516.627	19.3458
	±1σ	32.5177	29.7542
LONG 14 15-30	20009	755.113	39.1271
	±1σ	54.189	22.0213
LONG 14 30-45	20011	471.603	5.8811
	±1σ	35.8856	20.4616
LONG 14 TOTAL		**7987.973**	**381.895**
ERROR		**311.7641**	**54.9649**
LONG 24 0-5	20002	10893.3	540.536
	±1σ	721.837	71.2783
LONG 24 5-10	20006	779.741	17.1706
	±1σ	54.3176	15.7859
LONG 24 10-15	20003	110.492	10.6731
	±1σ	11.2173	10.8746
LONG 24 15-30	20004	227.918	25.0607
	±1σ	22.3268	21.2507
LONG 24 30-45	20005	134.342	16.7524
	±1σ	18.9729	22.9524
LONG 24 TOTAL		**12145.79**	**610.1928**
ERROR		**724.5573**	**80.16516**
LONG 34 0-15	10015	4906.55	213.2
	±1σ	270.01	24.5
LONG 34 15-30	10016	96.796	33.3694
	±1σ	23.4439	22.161
LONG 34 30-45	10017	97.6432	0.8551
	±1σ	19.3935	18.7594
LONG 34 TOTAL		**5100.989**	**247.4245**

ERROR		**271.7188**	**37.99046**
LONG 44 0-5	10021	3769.1	193.601
	±1σ	251.119	19.7697
LONG 44 5-10	10022	2827.57	119.238
	±1σ	189.599	18.2689
LONG 44 10-15	10023	670.732	8.9417
	±1σ	47.2165	13.7446
LONG 44 15-30	10024	538.922	20.5299
	±1σ	45.844	26.9247
LONG 44 30-45	10025	251.468	16.0329
	±1σ	26.9378	21.3899
LONG 44 TOTAL		**8057.792**	**358.3435**
ERROR		**322.5915**	**45.78182**
LONG 54 0-5	23007	5905.43	254.07
	±1σ	78.2133	130.716
LONG 54 5-10	20016	1282	426.94
	±1σ	120	45.99
LONG 54 10-15	23008	595.526	18.025
	±1σ	26.8253	25.1465
LONG 54 15-30	20017	583.984	51.578
	±1σ	42.3921	19.5404
LONG 54 30-45	20018	644.657	-3.9798
	±1σ	46.5195	-20.668
LONG 54 TOTAL		**9011.597**	**746.6332**
ERROR		**158.739**	**143.677**
LONG 64 0-15	10032	7912.57	408.951
	±1σ	526.881	37.5807
LONG 64 15-30	10033	659.485	34.1371
	±1σ	49.4176	21.0936
LONG 64 30-45	10034	500.409	30.4982

	$\pm 1\sigma$	39.3038	19.4397
LONG 64 TOTAL		**9072.464**	**473.5863**
ERROR		**530.651**	**47.27738**

Sample Name	File No.	Activity - Bq m^{-2}									
		^{241}Am	^{208}Tl	^{214}Bi	^{137}Cs	^{134}Cs	^{228}Ac	^{228}Ac	^{40}K	^{214}Bi	^{208}Tl
		59.6 keV	**583 keV**	**609 keV**	**662 keV**	**796 keV**	**911 keV**	**969 keV**	**1462 keV**	**1764 keV**	**2615 keV**
CUR 1 0-5	10081	11	84.94575	401.7825	9526.225	385.2238	185.7175	221.9775	4587.688	627.4663	100.1333
	±1σ	11	16.33	63.997	649.695	30.42838	58.47275	148.2263	307.365	170.8688	26.39325
CUR 1 5-15	10082	10.72043	250.8538	995.5038	2988.863	112.3125	718.8563	498.765	7859.613	842.9138	277.1563
	±1σ	15.9745	25.90475	106.2646	207.1025	22.24375	100.2206	258.7913	518.4963	296.12	51.68875
CUR 1 15-30	10092	-44.4475	473.4513	2040.113	1348.188	84.19963	1009.754	1439.975	20528	2102.425	439.9625
	±1σ	-28.4963	42.38175	175.1575	103.1508	33.92763	168.93	429.73	984.4213	547.21	84.75325
TOTAL		-22.7271	809.2508	3437.399	13863.28	581.7359	1914.328	2160.718	32975.3	3572.805	817.252
±1σ		34.47058	52.28707	214.6344	689.663	50.71247	204.9404	523.0792	1154.295	645.2302	102.7202
ART 1 0-5	10083	-8.77029	3.121743	-18.53	2528.729	110.262	23.94629	-217.3	-1258	67.98043	-6.71329
	±1σ	-7.84743	14.98586	-60.53	168.79	15.51014	58.55914	-153.929	-264.014	155.0714	-22.2529

ART 1 5-15	10084	-7.07814	107.9959	430.8886	1384.981	36.48229	352.1829	411.5914	3767.386	324.26	87.37486
	±1σ	-7.49886	12.01664	48.18243	96.23343	10.14226	46.58243	119.4201	238.2343	125.5551	21.46529
ART 1 15-30	10094	-31.7686	118.512	894.5157	1519.771	22.039	571.5043	640.2014	2545.471	920.5514	109.47
	±1σ	-20.0543	30.706	126.0164	109.0399	26.823	120.5586	316.99	579.5629	355.0057	51.04371
TOTAL		-47.617	229.6296	1306.874	5433.481	168.7833	947.6334	834.4929	5054.857	1312.792	190.1316
±1σ		22.80328	36.21925	147.8701	222.8018	32.6022	141.8924	372.0724	679.9649	407.2349	59.67754
DRA 1 0-5	20080	-23.1786	211.8429	795.6714	8260.357	366.0214	815.3743	751.4029	13457.29	821.57	342.3129
	±1σ	-19.7543	30.80829	134.823	567.4157	55.01643	101.0071	192.3543	566.3529	297.5043	50.89529
DRA 1 5-15	20081	-69.86	594.3829	2092.514	5998.014	184.0114	1961.829	1926.343	39623	1673.229	662.55
	±1σ	-40.9171	71.02171	309.2614	438.0843	55.51443	206.4057	400.26	1359.46	580.7414	94.50214
DRA 1 15-30	20092	-5.39243	866.2943	3187.614	1564.329	142.821	2601.429	3236.143	51823.71	2274.143	960.58

	±1σ	-50.1557	99.321	452.64	131.3607	66.32071	269.9429	610.1214	1776.057	749.2943	128.0177
TOTAL		-98.431	1672.52	6075.8	15822.7	692.8539	5378.631	5913.889	104904	4768.941	1965.443
±1σ		-110.827	201.151	896.7244	1136.861	176.8516	577.3557	1202.736	3701.87	1627.54	273.4151
SHA 1 0-5	20082	-32.0129	227.5171	736.4829	4471.329	185.9529	796.8486	971.55	12487.37	732.1671	247.8571
	±1σ	-20.08	30.59386	125.3057	318.0229	34.91971	94.967	204.7557	533.73	275.3686	44.10829
SHA 1 5-15	20083	17.70343	376.4043	1847.343	3045.786	168.4586	1419.224	1273.199	24859.14	1378.117	532.0514
	±1σ	29.64329	46.85829	261.3529	230.7	40.64657	146.3086	276.6271	891.6057	435.11	70.79914
SHA 1 15-30	20093	-15.7757	156.75	665.81	431.9571	-16.5086	506.4929	505.9814	10278.64	580.0714	180.8343
	±1σ	-13.8561	19.99257	98.02029	37.83529	-15.6629	58.21414	109.9203	385.0529	185.76	26.03257
TOTAL		-30.0851	760.6714	3249.636	7949.071	337.9029	2722.566	2750.73	47625.16	2690.356	960.7429
±1σ		-4.29286	97.44471	484.6789	586.5581	59.90343	299.4897	591.3031	1810.389	896.2386	140.94
BEN 1 0-5	10085	15.508	9.829914	-14.7414	4846.386	219.7586	-16.2414	-117.376	-1118.19	145.5957	-60.4729

	±1σ	6.420043	10.84496	-44.3429	322.0729	18.10557	-41.5686	-107.946	-193.457	108.7116	-19.9114
BEN 1 5-15	10086	-1.90971	23.861	94.72429	1983.657	67.11886	-7.533	312.8086	-1263.01	358.2	5.248557
	±1σ	-8.78029	14.60771	61.08543	134.597	14.1645	-61.0457	150.4971	-280.186	174.5371	24.65171
BEN 1 15-30	20091	21.84643	87.15543	77.49914	1509.471	15.89386	339.0086	521.7229	1308.497	207.4657	149.4571
	±1σ	17.12271	23.79443	84.97514	106.7333	28.14271	83.69071	174.2357	394.8543	271.8629	44.45914
TOTAL		35.44471	120.8463	157.482	8339.514	302.7713	315.2341	717.1557	-1072.7	711.2614	94.23284
±1σ		14.76247	49.2471	101.7177	563.4031	60.41279	-18.9236	216.7871	-78.7886	555.1116	49.19943
ING 1 0-5	10087	-8.561	416.6986	1599.743	6654.7	287.2543	1436.586	1774.6	12338.26	2252.671	390.2157
	±1σ	-23.0571	38.18357	152.1871	462.2357	36.374	143.6871	377.7986	731.2643	504.9643	75.50071
ING 1 5-15	10088	-44.7	808.3971	4109.443	5444.386	290.2086	3408.357	2520.157	32577.71	5733.157	991.0429
	±1σ	-49.6629	79.40443	320.07	397.1857	65.91971	329.0014	797.85	1555.971	1155.323	166.05
ING 1 15-30	10096	-79.9514	2109.457	8958.429	2502.843	336.0914	6007.343	7093.457	77084.14	9002.971	2132.486

	±1σ	-97.4586	150.71	619.0243	214.8414	106.1607	580.82	1487.6	3400.9	2022.671	358.4657
TOTAL		-133.212	3334.553	14667.61	14601.93	913.5543	10852.29	11388.21	122000.1	16988.8	3513.744
±1σ		-170.179	268.298	1091.281	1074.263	208.4544	1053.509	2663.249	5688.136	3682.959	600.0164
NUT 1 0-5	10090	-16.2729	272.0871	1560.657	2438.586	135.4427	917.85	518.8814	13808.03	1683.357	352.6314
	±1σ	-26.3771	41.024	169.4557	175.0043	34.29286	163.5914	418.6914	852.5657	483.08	78.20043
NUT 1 5-15	10091	16.28743	615.8971	2536.657	2351.514	75.40143	1828.6	1757.057	30182.71	3025.929	578.89
	±1σ	46.29057	69.30943	276.3586	179.6829	55.67971	270.25	697.87	1499.157	820.6157	124.6739
NUT 1 15-30	10093	-182.886	1698.429	5920.771	874.8986	239.9829	5658.586	4212.529	75507.29	4717.129	2047.686
	±1σ	-128.046	170.7743	658.22	158.2671	135.3966	668.7686	1734.514	3806.714	1845.786	384.52
TOTAL		-182.871	2586.413	10018.09	5664.999	450.827	8405.036	6488.467	119498	9426.414	2979.207
±1σ		-108.132	281.1077	1104.034	512.9543	225.3691	1102.61	2851.076	6158.437	3149.481	587.3943
BOR 1 0-5	20089	9.6078	168.3457	886.0314	1061.149	54.36114	641.0514	764.9143	13215.76	806.5929	257.34

	±1σ	23.81886	29.46014	145.9914	85.92943	31.07314	100.6794	204.9257	615.0429	329.88	51.93871
BOR 1 5-15	10089	-15.74	213.6086	1244.01	1224.767	86.49586	737.1414	807.6614	13177.01	1064.241	273.5771
	±1σ	-24.6929	33.17557	136.8884	94.77357	28.422	131.3433	340.5214	759.8271	394.5714	63.47329
BOR 1 15-30	10095	108.1983	909.64	3259.514	2746.371	317.3657	2470.343	2841.057	48521.57	5072.171	975.4486
	±1σ	84.29257	101.4383	418.85	230.3929	84.55657	412.2343	1049.821	2408.357	1309.506	199.8429
TOTAL		102.0661	1291.594	5389.556	5032.287	458.2227	3848.536	4413.633	74914.34	6943.006	1506.366
±1σ		83.41857	164.074	701.7299	411.0959	144.0517	644.257	1595.269	3783.227	2033.957	315.2549
DUN 1 0-5	20084	13.63687	111.6784	394.9729	3862.086	191.3843	395.6457	490.5857	5584.2	493.7129	169.21
	±1σ	13.37647	19.38743	80.388	265.7143	31.18329	63.41529	131.4316	328.8329	199.7714	33.74271
DUN 1 5-15	20085	-33.8786	201.2757	941.07	2608.814	92.698	744.0571	791.8386	12212.23	936.6314	278.4743
	±1σ	-22.7043	31.57	154.1171	186.9386	32.852	105.2231	212.1429	596.8129	333.9586	52.82657
DUN 1 15-30	20094	-51.1843	281.65	684.6514	430.8457	19.11414	904.6814	850.2443	7895.114	519.6057	316.76

	±1σ	-23.8286	38.22314	138.8193	43.36743	33.19929	119.299	228.6429	556.8157	341.5314	58.19414
TOTAL		-71.426	594.6041	2020.694	6901.746	303.1964	2044.384	2132.669	25691.54	1949.95	764.4443
±1σ		-33.1564	89.18057	373.3244	496.0203	97.23457	287.9374	572.2173	1482.461	875.2614	144.7634
CRO 1 0-5	20086	0.092957	70.73629	168.81	7741.814	342.0357	223.9	161.1643	2757.386	271.7086	93.40429
	±1σ	8.736714	12.7965	46.26114	520.2057	45.77214	40.43871	73.465	200.6814	129.0066	20.95671
CRO 1 5-15	20087	16.48929	212.6257	719.6486	3373.943	131.8356	763.5914	685.3657	8180.257	1502.529	258.3829
	±1σ	17.47286	28.07071	119.1963	238.3129	29.55286	89.177	168.6643	429.3857	338.8229	42.54343
CRO 1 15-30	20096	-20.81	298.63	1395.333	522.6257	101.482	1048.963	1263.63	17208.71	1847.286	397.9457
	±1σ	-23.0771	37.76686	200.3929	48.31814	31.26457	115.503	252.2714	665.2057	417.1957	56.48714
TOTAL		-4.22776	581.992	2283.791	11638.38	575.3533	2036.454	2110.16	28146.36	3621.523	749.7329
±1σ		3.132429	78.63407	365.8503	806.8367	106.5896	245.1187	494.4007	1295.273	885.0251	119.9873

BAR 1 0-5	20088	0.2829	44.08986	-72.0143	12274.94	497.4014	160.6071	371.8657	2793.657	76.75686	180.3043
	±1σ	24.90914	27.14643	-101.179	914.8543	73.15343	94.45871	184.5129	436.02	297.5271	47.68414
BAR 1 5-15	20090	-14.9043	3.722457	49.99114	2098.729	63.99414	183.24	237.6814	902.77	180.97	82.85914
	±1σ	-9.93357	12.94706	50.05371	141.7949	18.74971	48.83471	97.37943	240.5086	169.5371	26.55029
BAR 1 15-30	20095	12.63699	71.96014	311.9443	1777.543	40.47614	328.15	493.4457	2939.386	-2.84486	151.4171
	±1σ	16.664	22.61	94.05814	124.4829	27.98	82.52129	170.9643	418.6886	-280.857	44.55186
TOTAL		-1.9844	119.7725	289.9211	16151.21	601.8717	671.9971	1102.993	6635.813	254.882	414.5806
±1σ		31.63957	62.70349	42.93329	1181.132	119.8831	225.8147	452.8566	1095.217	186.2071	118.7863

APPENDIX D.

During the course of the Scottish Office aerial survey in February 1993, a return visit was made to Caerlaverock merse calibration site. A comparison between February 1992 and February 1993 is made below (figure D.1 and D.2), for a 16 litre detector, and good agreement is observed for ^{137}Cs and total gamma-ray net count rate.

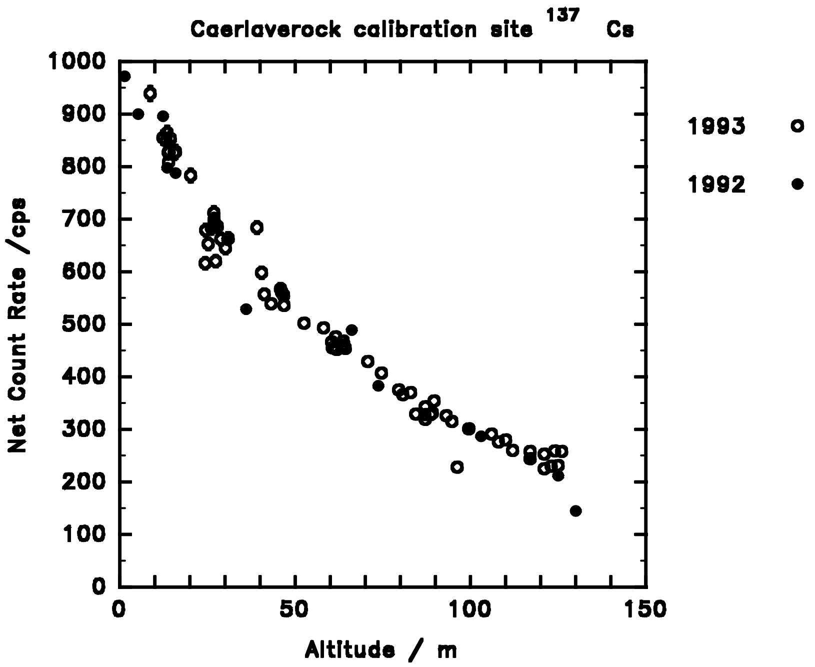

Figure D.1

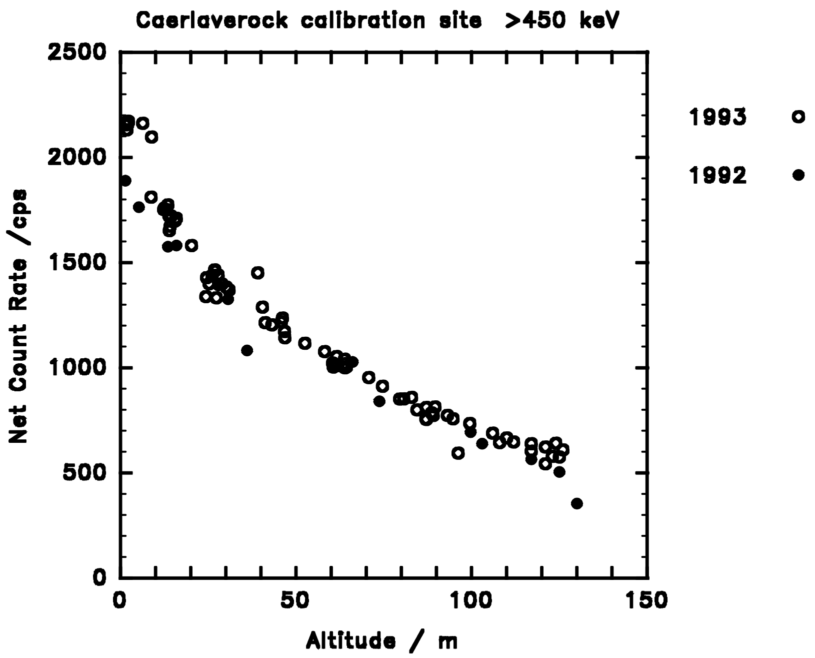

Figure D.2